EXPLORATORY DRILLING PRACTICES AND COSTS AT WESTERN URANIUM DEPOSITS

By D. E. Redmon

* * * * * * * * * * * information circular 7944

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary

BUREAU OF MINES
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This publication has been cataloged as follows:

Redmon, Donald E

Exploratory drilling practices and costs at western uranium deposits. [Washington] U.S. Dept. of the Interior, Bureau of Mines [1960]

iv, 68 p. illus., tables. 26 cm. (U.S. Bureau of Mines. Information circular 7944)

Bibliography: p. 67–68.

1. Uranium ores—U.S.—The West. 2. Boring. I. Title. (Series)

TN23 U71 no. 7944 622.06173

U.S. Dept. of the Int. Library

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CONTENTS

	Page
Introduction	1
Acknowledgments	2
Summary of drill equipment usage	2
Contract drilling	5
Churn drilling	6
Rotary drilling	9
Diamond bits	9
Utilization of compressed-air medium in rotary drilling	10
Compressed air requirements	13
Use of air medium in core drilling	18
Practice at Beaver Mesa	20
Practice at Buckskin Mountain	21
Wire-line core drilling	24
Operation of wire-line equipment	26
Practice at Hauber property	28
Practice at Jackpile mine	32
Practice at Carr Fork operation	34
Practice with NX wire-line equipment in 6-3/4-inch-diameter holes	36
Recovering core with the freezing method	37
Practice at the Aljob property	40
Recovering core from loosely consolidated formations with a pilot-type bit	45
Practice at the Day-Loma claims	47
Pneumatic-percussive drilling	50
Truck-mounted pneumatic-percussive drills	50
Practice at Dulaney Mining Co	50
Practice at the Bean claims	52
Down-the-hole pneumatic-percussive drills	53
Sampling unconsolidated formations with a dry-hole digger	56
A comparison of noncore drilling methods	59
Rotary-table drill rigs	59
Swivel-head drill rigs	59
Churn-drill rigs	59
Sampling methods and reliability	60
Exploration, pit planning and mining control by drilling at Lucky Mc Uranium Corp	61
Dry sampling for mining control	61
Using dry-hole digger for mining-control sampling	63
Other sampling methods	63
Description of materials, parts--Lucky Mc Dust Collector	64
Bibliography	67

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ILLUSTRATIONS

Fig.		Page
1.	Typical swivel-head rotary-drill rig, truck-mounted..	3
2.	Typical rotary-table shot-hole rig, truck-mounted....	4
3.	Churn-drill rig near Naturita, Colo. Courtesy of Franklin-Cowan Co.....	8
4.	Liquid petroleum gas container adapted for use as water tank for water injector. Courtesy of R. J. Colquitt, drilling contractor.....	12
5.	Ducon dust collector used to trap drill cutting and dust from a pneumatic-percussive drill. Courtesy of Lippoth and Wein Drilling Co.....	14
6.	Sample catcher used with rotary-table drill rigs. Deflector similar to Winter-Weiss dust hood. Courtesy of Teton Exploration Co.....	15
7.	Tandem arrangement of a Lucky Mc box-type dust collector and a cone-type collector.....	16
8.	Graph for solution of air-volume requirements for noncore drilling.....	19
9.	Typical diamond bit (4-1/2- by 1-7/8-inch) for use with air medium. Note large discharge courses.....	20
10.	Truck-mounted wagon drill rig with air-powered rotary drill motor in place of pneumatic-percussive rock drill. Inset shows closeup of the drill motor.....	23
11.	Nomenclature of wire-line core barrel and overshot assembly.....	25
12.	Wire-line inner tube assembly removed from hole. Note sharp bend where overshot connects to spear-head of inner tube assembly. E. L. Longyear Co. rig. Jackpile Mine property, Grants district, N. Mex.....	27
13.	Dropping NX wire-line inner tube assembly. Note spearhead emerging from overshot assembly. L. Materi drill rig. Hauber property, Crook County, Wyo.....	29
14.	Wire-line core barrel inner tube assembly at hole collar with AX core from 1,604-foot depth. Wire-line hoist in right foreground.....	35
15.	Oil-chilling tank in bulldozed pit beside drill site. Aljob property, Gas Hills district, Wyo.....	39
16.	Frozen core removed from core barrel. Courtesy of Utah Mining Corp.....	41
17.	Thawed specimen of a core recovered by the freezing method.....	43
18.	Using chunks of dry ice to chill diesel oil for frozen-core drilling. Note liquid turbulence caused by evaporation of dry ice.....	44
19.	Section of pilot-type bit and bottom end of 4-1/2- by 3-inch core barrel. Courtesy of Christensen Diamond Products Co.....	46

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ILLUSTRATIONS (Con.)

Fig.		Page
20.	Pilot-type bit for cutting 3-inch core. Note face discharge ports and replacement pilot bits, diamond or tungsten carbide insert	47
21.	Core extruded from inner tube by drill-fluid pressure	49
22.	Cans used to catch samples of drill cuttings and dust. Dust seal in right foreground rests on top of deflector tee during drilling. Note weld beads on rod connector above rod-guide unit	51
23.	Typical cone-type dust collector arrangement	53
24.	A down-the-hole machine, with 4-3/4-inch, X-type, carbide insert bit, connected to kelly on a chain-feed drill rig	54
25.	Air flushing dust and rock particles from a 4-3/4-inch hole drilled with a down-the-hole machine	55
26.	Dry-hole digger used to drill 15-inch-diameter holes for mine-control sampling at the Lucky Mc mine	57
27.	Dropping 12-inch bucket into hole. Note scraper-type bit on bottom of 18-inch bucket in right foreground	58
28.	Drillhole layout, Lucky Mc Uranium Corp., Fremont County, Wyo	62
29.	Nominal dimensions and structural details of Lucky Mc dust collector. Courtesy of Lucky Mc Uranium Corp	65
30.	Christensen core barrel and pilot-type bit used to core-drill unconsolidated sediments for mining-control samples	66

TABLES

1.	Noncore drilling, prices per foot, 1958	5
2.	Core drilling with diamond bits, prices per foot, 1958	6
3.	Direct cost, contract drilling, Big Indian mining district, Utah, 1956-57	7
4.	Rotary-drilling trends, Colorado Plateau, 1954-57	8
5.	E. J. Longyear wire-line core-barrel specifications.	26
6.	Time check, core drilling with wire-line equipment, Hauber property, Wyo., 1957	31
7.	Noncore drilling and drilling with NX-size L-series core barrel. Hauber property, Wyo., 1957	32
8.	Noncore drilling and drilling with NX-size wire-line equipment. Hauber property, Wyo., 1957	32
9.	Summary of footage data for 31 holes, Jackpile mine, Grants district, N. Mex., 1957	33

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TABLES (Con.)

		Page
10.	Operational data, drilling with NX wire-line equipment, Jackpile mine, Grants district, N. Mex., 1957-58	33
11.	Core-drilling results; wire-line equipment, Jackpile mine, Grants district, N. Mex., 1957-58	33
12.	Core-drilling results, conventional equipment and wire-line equipment, Jackpile mine, Grants district, N. Mex	34
13.	Direct costs of frozen-core drilling. Vitro Uranium Co., Jan. 1956	45
14.	General stratigraphic section on Day-Loma claims, Wyo	48
15.	Drilling progress with a dry-hole digger	58
16.	Ore reserve estimates compared with ore produced, Lucky Mc mine, 1955-56	61

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EXPLORATORY DRILLING PRACTICES AND COSTS AT WESTERN URANIUM DEPOSITS[1]

by

D. E. Redmon[2]

INTRODUCTION

Exploration of hidden mineral deposits becomes increasingly important as known ore reserves are depleted. The primary objective in any exploratory program is to obtain enough reliable information to evaluate accurately the potential of the mineral deposit. Constant improvement in equipment and technique has established drilling as one of the most valuable methods of exploration.

This paper presents the results of studies of several drilling methods currently used in the search for uranium deposits in sedimentary formations from surface drill sites. Also presented is a description of drilling with wire-line equipment from an underground location in metamorphic rocks. The studies were conducted in the Colorado Plateau area and in northwestern New Mexico and Wyoming. Statements of a general nature pertain to conditions or situations existent in those areas.

Data concerning drilling done by different drill crews, working with different types of equipment and under a wide range of conditions, cannot be combined to present accurately overall average performance. The decision to study several different methods was made with the thought that the various techniques used by the drillers to solve their specific problems might be applied to similar problems in other localities. Some of the rather detailed descriptions and discussions might seem academic to persons directly engaged in exploratory drilling, but we hope that this information will contribute to the improvement of techniques and a better utilization of methods now in use.

References to specific equipment used in the various drilling operations are made only to describe accurately equipment usage and do not constitute Bureau of Mines approval or preference.

1/ Work on manuscript completed March 1959.

2/ Mining methods research engineer, Bureau of Mines, Region III, Denver, Colo.

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ACKNOWLEDGMENTS

The data used in this report were obtained through the cooperation of drilling contractors and the managerial staffs of mining companies and equipment manufacturers. Their assistance is gratefully acknowledged. Special credit is given to those mentioned in the text of this publication. Many others gave freely of their knowledge, experience, and opinions; the information thus gained is deeply appreciated.

SUMMARY OF DRILL-EQUIPMENT USAGE

Exploratory drilling for uranium increased steadily from 1948 until 1956 when an estimated 8,720,000 feet was drilled.3/ Contractors competing for the drilling jobs recognized the need for portable equipment and improved technology. Surplus army vehicles, such as halftracks and 6 by 6 trucks, were utilized, when available, as drill-equipment carriers. Truck-mounted drill rigs have now almost completely replaced skid-mounted rigs for drilling from surface locations.

One type of rotary drill, usually called a diamond drill, is designed primarily for drilling with diamond-studded bits. Bit advance is controlled at the swivel head by a geared differential feed screw or by a hydraulic drive rod. Flush-coupled drill rods pass through the feed screw or drive rod and are clamped in a jawed chuck connected to the end of the screw or drive rod. Rotation of the chuck turns the drill rods and bit (fig. 1). This type of drill is capable of attaining high rotation speeds and is especially suited for drilling with diamond bits through dense crystalline rocks such as schist, gneiss, or granite. Diamond drills are available in various models for drilling from underground or surface drill sites. Also, these drills are frequently used for noncore drilling with roller or drag-type bits.

Another type of rotary drill, designed primarily for seismograph shothole drilling, is used extensively for exploratory drilling from surface locations. In this type, pressure on the bit is applied by hydraulic cylinders or pulldown mechanisms. Rotation of the drill bit is accomplished by a kelly bar that slides through a turntable and is attached to the drill rods. The drills are especially applicable to noncore drilling with rock bits or drag bits. However, they are also satisfactory for core drilling with diamond bits at rotation rates in the range of 20 to 250 r.p.m. (fig. 2).

Truck-mounted pneumatic-percussive drills are especially useful for exploratory drilling in dry formations to depths less than 250 feet, if dust and rock chips are acceptable for samples. Such drill rigs consist essentially of a heavy drilling machine mounted on a long-change shell, which constitutes the drill-rig mast. An air compressor, arranged for single or dual pressure, is normally part of the rig. The unit is a compact, versatile version of a wagon drill.

3/ AEC Press Release, Domestic Uranium Program in 1956. 7 pp.

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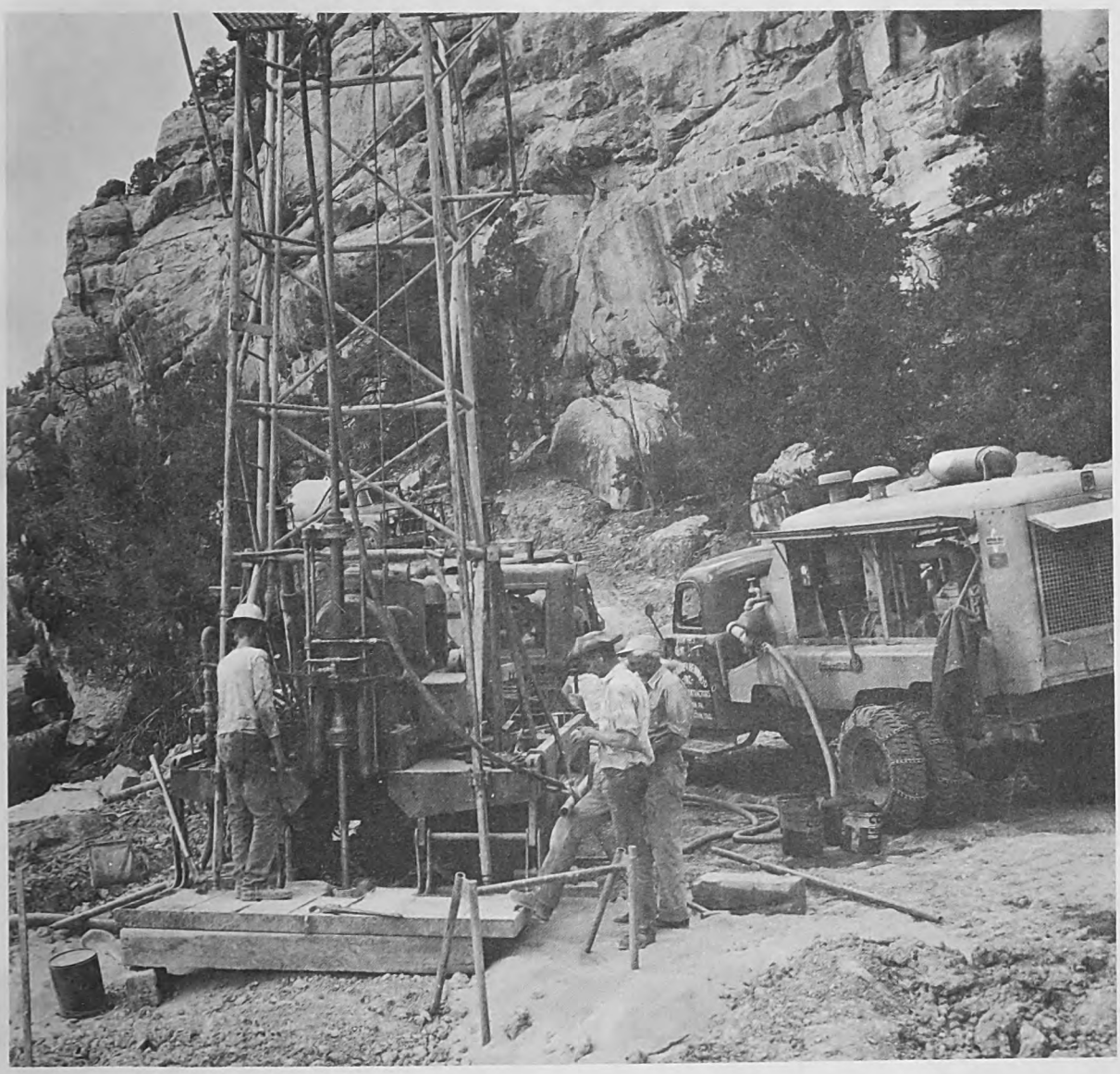

FIGURE 1. - Typical Swivel-Head Rotary-Drill Rig, Truck-Mounted.

Mobile churn-drill rigs are used extensively to drill quarry blastholes, mine ventholes, power-access openings, and water wells. Their application in exploratory drilling is primarily for drilling through overburden and hard formations preparatory to rotary core or noncore drilling. If proper precautions are taken, accurate large-volume samples from deep holes can be obtained by churn drilling.

Other types of drills used in exploratory work include the auger or bucket drills and down-the-hole pneumatic-percussive drills. The use of auger or bucket types is limited to soft formations. Down-the-hole drills are in a relatively early stage of development, and their applications to exploratory drilling problems have not yet been fully determined.

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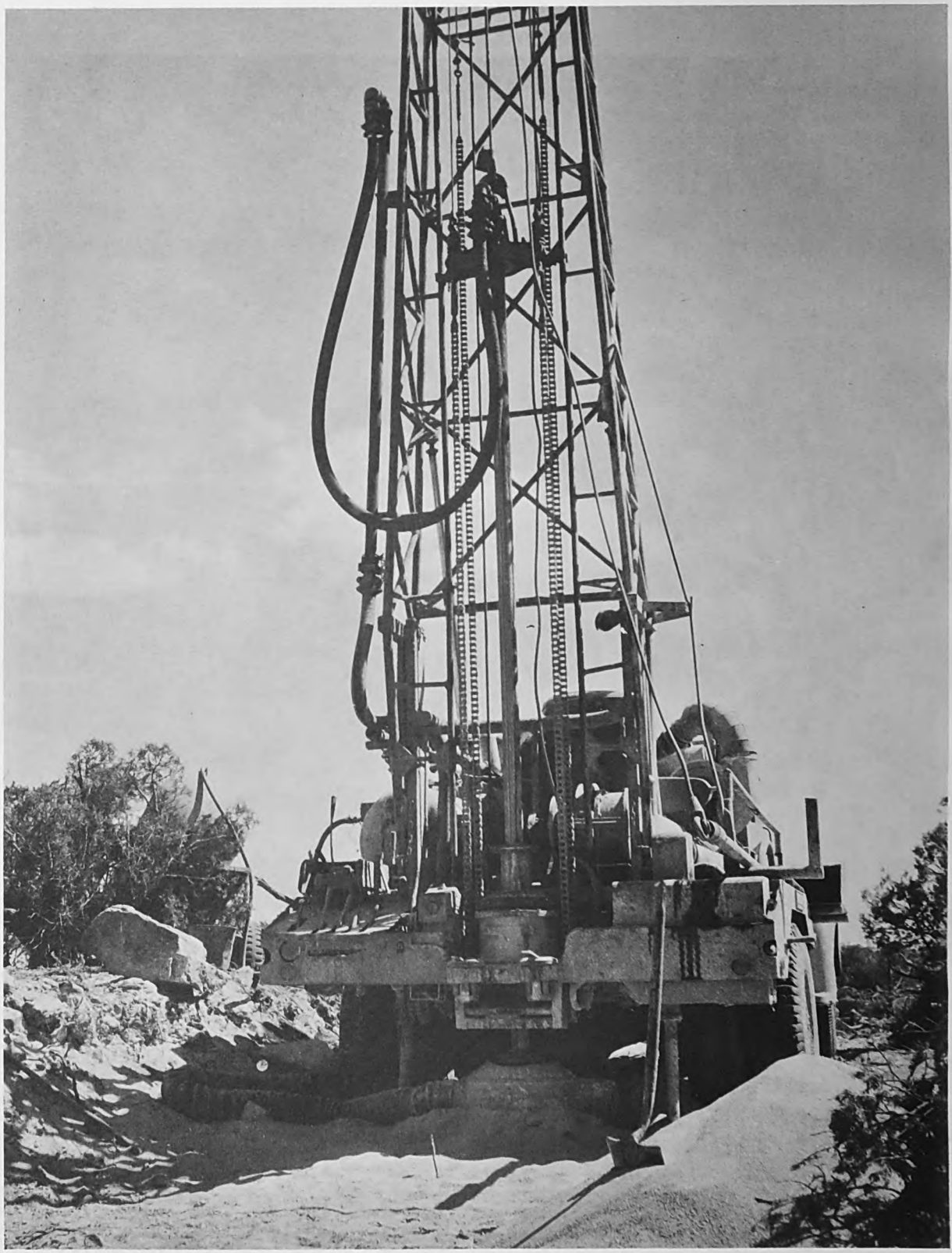

FIGURE 2. - Typical Rotary-Table Shot-Hole Rig, Truck-Mounted.

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CONTRACT DRILLING

In the area studied, most exploratory drilling from surface sites is done by contracting firms. Items usually specified in drilling contracts are listed in chapter 20 of Diamond Drill Handbook (5, pp. 486-506).4/ This handbook contains much other valuable information that is applicable to all types of drilling.

Cutthroat bidding for a drilling contract is often damaging to all parties concerned; prices bid may be too low to permit efficient performance. Information gained from poorly executed exploratory drilling may be misleading. It is advisable to engage a reputable driller at a fair price.

In new areas it is common practice to hire a contractor's drill rig, auxiliary equipment, and operators, on an hourly or daily basis and to pay for all expendable supplies such as drill mud, bits, and lost casing. After subsurface conditions are known or new drilling practices are established, additional drilling may be done on a contract basis.

Contract drilling prices, usually quoted on a per-foot basis, depend on type of drilling, size and depth of hole, method of sampling, and anticipated ground conditions. Other considerations include transportation, location of drill sites, topography, and total footage to be drilled.

The prices given in tables 1 and 2, for contract drilling from surface sites, indicate the range in rates prevailing on the Colorado Plateau and in Wyoming and New Mexico in 1958.

TABLE 1. - Noncore drilling, prices per foot, 1958[1/]

Depth feet	Churn drill	Pneumatic-percussive	Rotary (air and/or water medium)	Dry-hole digger (15-in. dia.)
0-500	$1.75 - $4.00	2/$0.40 - $1.80	3/$0.70 - $2.25	4/$1.00 - $10.00
500-1,000	3.50 - 6.00	-	3/ 1.60 - 5.00	-
1,000-2,000	-	-	2.50 - 6.00	-

1/ 3- to 6-1/2-inch-diameter holes unless noted otherwise.
2/ Rarely exceeds 250-foot depth. May not be completed if wet ground is encountered.
3/ Price range reflects increased charges when noncore drilling is to be followed by core drilling.
4/ Maximum depth attained, 140 feet.

Contract drilling prices may be higher or lower than those listed in tables 1 and 2, under unusual circumstances.

4/ Underlined numbers in parenthesis refer to items in the bibliography at the end of this report. Page references refer to pages in the items and not in this report.

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TABLE 2. - Core drilling with diamond bits, prices per foot, 1958[1/]

Depth feet	Conventional	Air medium	Wire-line (AX to NX)	Frozen core	Pilot-type bit
0-500	$1.80 - 4.00	$1.75 - 4.00	$1.75 - 5.00	$15.00 - 20.00	$15.00 - 20.00
500-750	4.00 - 9.00	4.00 - 8.00	3.00 - 5.50	17.00 - 25.00	17.00 - 25.00
750-1000	7.00 - 12.00	7.00 - 12.00	5.00 - 7.00	-	-

1/ 2- to 4-1/2 inch-diameter holes.

Table 3 presents cost figures furnished by a drilling contractor operating in southeastern Utah. These costs exclude charges for depreciation and supervision.

Table 3 reveals that direct costs range from $1.27 to $1.81 per foot. The higher figure applies to the deepest drilling--two holes where the average depth exceeded 1,000 feet. Also noteworthy is the high cost of diamond bits per foot of hole, compared to the cost of rock bits.

As most of the shallow ore bodies had been explored by 1954, average drilling depths in recent years have been considerably increased. Reaching the deeper ore horizons requires penetration of a greater proportion of waste rock. This situation tends to result in lower overall unit costs because it involves more noncore drilling.

Data given in table 4, pertaining to rotary drilling, were obtained from drilling records at several properties in western Colorado and eastern Utah. The data show that 50.3 percent of the footage drilled in 1954 was noncore and that the percentage of noncore drilling had increased to 76.4 percent by 1957. The corresponding average depths were 216 feet and 358 feet.

CHURN DRILLING

A churn drill employs a heavy cutting tool that is alternately lifted and dropped by a wire or fibre rope. Factors affecting churn-drilling operations are described in a Bureau of Mines Report of Investigations (19).

Churn drills are largely used for drilling oil wells, large-diameter blastholes, mine-ventilation holes, and water wells, from surface drill sites. Probably their most common use in recent years has been for blasthole drilling in open-pit mines and quarries.

Ordinarily, churn drilling is slow and expensive compared to rotary drilling. However, the churn drill has been used to advantage in conjunction with the rotary drill in exploring for uranium. A few properties have been explored solely by churn drilling (fig. 3).

The churn drill is often used in hard formations where rotary-bit costs are excessive, or in highly fractured ground where air or water circulation might be lost. Loosely consolidated material in which numerous boulders and hard pebbles occur is especially difficult and expensive to drill with rotary equipment; under these conditions, the churn drill is frequently a satisfactory alternative. If proper precautions are taken, accurate large-volume samples can be obtained by churn drilling.

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TABLE 3. - Direct cost, contract drilling, Big Indian mining district, Utah, 1956-57

Property	No. holes	Footage		Bit costs		Wages	Fuel and lubricant	Drill pipe	General expense[1]	Overall cost per foot
		Non-core	Core	Rock	Diamond					
1.....	3	2,210	70	$ 276.50	$ 167.46	$ 1,085.67	$ 221.27	$0.23	$1,051.04	$1.46
2.....	10	7,486	404	1,425.48	288.36	4,121.74	1,206.36	.23	2,457.75	1.44
3.....	9	2,230	-	180.00	-	1,112.06	190.90	.23	1,910.60	1.69
4.....	2	2,007	105	584.00	124.76	1,153.03	310.45	.23	1,162.24	1.81
5.....	3	1,710	139	132.50	280.06	851.53	188.24	.23	762.34	1.43
6.....	5	2,700	144	282.00	227.66	1,194.02	355.50	.23	910.08	1.27
7.....	3	1,390	-	140.00	-	560.88	171.12	.23	736.70	1.39
Total	35	19,733	862	$3,020.48	$1,088.41	$10,128.43	$2,643.84		$8,990.75	
Average cost per foot				[2]/0.15	[3]/1.26	0.49	0.13	0.23	0.44	1.49

1/ Includes such items as camp costs, engineer's fees and telephone charges.
2/ Computed for noncore footage only.
3/ Computed for core-drilled footage only.

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TABLE 4. - Rotary drilling trends, Colorado Plateau, 1954-57

Year	Footage	Hole depth average, feet	Percent, coring1/	Percent noncoring2/
1954.....	234,860	216	49.7	50.3
1955.....	384,804	322	34.4	65.6
1956.....	527,579	359	25.1	74.9
1957.....	461,730	358	23.6	76.4

1/ AX to NX size.
2/ 3- to 5-inch-diameter holes.

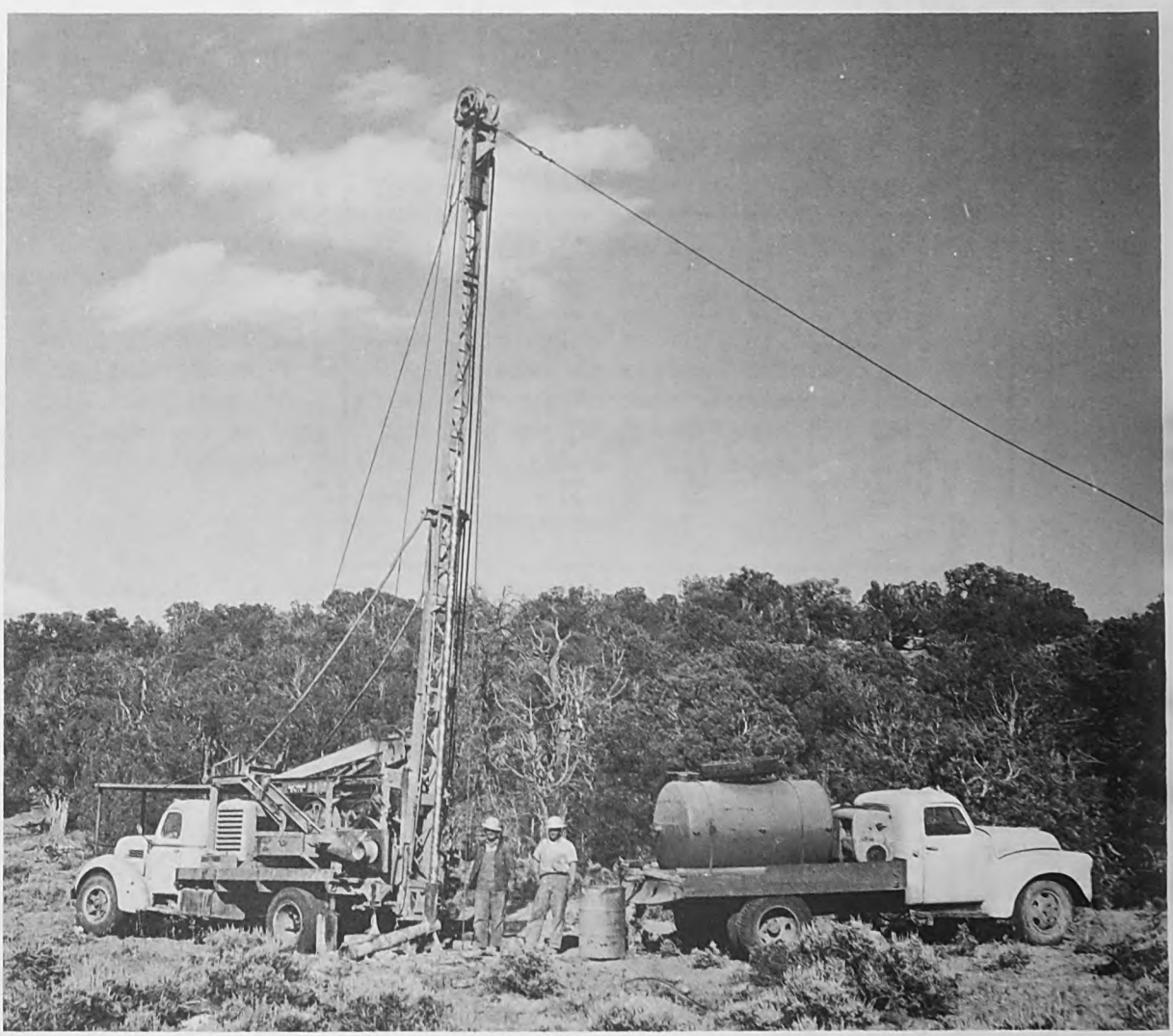

FIGURE 3. - Churn-Drill Rig Near Naturita, Colo. *(Courtesy of Franklin-Cowan Co.)*

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ROTARY DRILLING

Diamond Bits

Detailed performance and cost records have been kept since 1945 on diamond coring bits used on Bureau of Mines projects throughout the United States, including Alaska. Analytical reports have been issued covering bit performance in limestone and dolomite (8), schist (11), cherty limestone and cherty dolomite (12), gneiss (13), sandstone (14), and quartzite (18). In addition to general diamond-drilling information, the report presents specific data that justify the following conclusions:

1. In gneiss, schist, limestone, and dolomite: Diamond losses and bit costs, per foot drilled, lessen as the size of drill bort used is decreased from 8 to 10 stones per carat to 30 to 40 stones per carat.

   In sandstone: Bits set with 8- to 10-per-carat-size, AA-grade drill bort are more economical than those set with smaller size AA-grade diamonds or any size Congo stones.

   In quartzite, cherty limestone, and cherty dolomite: Diamond losses and bit costs per foot drilled decrease as the number of diamonds increases to more than 8 to 20 stones per carat.

2. At diamond prices used in calculating bit costs in the reports on drilling in schist, limestone, and dolomite, bits set with A-grade drill bort are more economical than those set with AA, AAA or Congo grades. At 1945-49 prices, bits set with Congo diamonds were the most economical for use in gneiss. At 1957 prices, for core drilling through quartzites, the lower grade, cheaper diamonds, such as Congos, were the most economical.

3. Loss of core in the hole adversely affects bit performance.

4. M bits consistently recover a higher percentage of core than bevel-wall bits.

5. M bits are more economical for use in sandstone and quartzite than bevel-wall bits.

6. In sandstone, a decrease in diamond size usually results in a decrease in feet driller per bit.

7. Except in sandstone, an increase in bit circumference usually is accompanied by an analogous increase in bit costs and diamond losses per foot drilled.5/

8. In unbroken homogeneous gneiss, the use of a high-cost hard matrix is not economical because the diamonds become polished before the matrix erodes.

5/ Only AX-size bits were used in gneiss.

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In schist, beryllium nickel is a more satisfactory matrix alloy than beryllium copper.

Bits set with beryllium nickel, beryllium copper, or powder-metal matrices were used for drilling in limestone and dolomite, sandstone, cherty limestone and cherty dolomite, and quartzite. No conclusive data were obtained relative to comparative costs.

9. In quartzite, cherty limestone, and cherty dolomite, orientation of diamonds in hard-vector directions in drill bits proved economically advantageous.

The aforementioned conclusions were based on data obtained from tests employing good diamond-drilling practice and technique. The numerous factors that contribute to optimum bit performance are described by Cumming (5, pp. 109-163).

Utilization of Compressed-Air Medium in Rotary Drilling

Information pertaining to costs, feet drilled per bit, penetration rates, bit design, bit loading, and rotation rates is found in publications on oil-well drilling. Much of the information contained in these publications is applicable to the type of drilling with which this report is concerned.

Results of experiments indicate that greater penetration rates and longer bit life can be expected if compressed air, instead of water, can be used as a flushing medium (17, p. 124). The high velocity of the air results in efficient cleaning of the hole. Rapid removal of rock chips from the bit minimizes wear on the bit teeth and allows more rapid penetration. Rapid removal of dust particles helps to extend bit-bearing service. Some roller-type bits are made in such a way that compressed air is discharged through the bearings from inside the bit body; this may prevent the entry of rock particles.

Conditions and factors suggesting the use of compressed air as a drilling medium are as follows:

1. Inadequate water supply.

2. Weather sufficiently cold to freeze water medium.

3. Hard formations in which liquid medium tends to allow accumulation of abrasive cuttings that cause excessive rock-bit wear.

4. Fractured or cavernous formations in which loss of circulating liquid would be excessive.

5. Soft formations in which the principal problem is rapid removal of the abundant cuttings.

6. Availability of compressors with adequate volume and pressure potentials.

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Excessive ground water discourages the use of compressed air as a flushing medium. After the bit has passed through a wet stratum, dust and dry rock chips adhere to the moist wall of the hole and form a constriction or mud collar which intereferes with airflow. The constriction may also prevent extraction of the drill bit. Penetration of a wet formation is indicated by a significant reduction in the amount of dust discharged from the hole and by the presence of mud pellets in the cuttings. Constrictions are also indicated by an increase in compressor outlet gage pressure.

The means of counteracting adverse drilling conditions brought about by a waterflow depends primarily upon the rate and expected duration of flow, effect of water on the formations penetrated higher in the hole, compressor capacity, extent and type of drilling below the wet zone, and the drilling characteristics of the underlying formations. If only the one aquifer is anticipated, and extensive drilling is to be done below the waterflow, casing or sealing the flow may be desirable. A seep or limited waterflow may be counteracted by one or a combination of the following methods:

1. Cease drilling and evaporate the water with the airflow. This method is effective only if the waterflow is not persistent.

2. Reduce the penetration rate and maintain the airflow volume to increase the ratio of air to cuttings.

3. Inject water to increase the ratio of water to cuttings. If enough water is injected with the compressed air (fig. 4) to make a mud slurry of the cuttings, the slurry can be discharged from the hole by the compressed air without adhering to the hole wall. For holes less than 5 inches in diameter, relatively small quantities of water are adequate for this purpose.

The encountering of a large flow of water is indicated by the presence of water in the discharged cuttings. A large flow usually will not cause difficulty if the compressed air pressure is adequate to lift the water from the hole and if the formations being drilled do not swell or slough on contact with water. Casing to seal off the waterflow might be required if disposal of the water is a problem.

Some bits are designed specifically for drilling with air medium. However, most rock bits can be used with either air or liquid drilling medium. The conventional bit, in which the medium is discharged to the cutters, is favored by some drillers. The jet-type rock bit, in which the medium is directed toward the hole bottom, is preferred by others. The jet-type bit is apparently best for drilling in the more abrasive formations. The short teeth on a bit designed for hard formations are believed to produce relatively small chips which may be readily removed by air medium (16, p. 114).

Bearing failure is an important factor in roller-bit cost. The bearing-surface area per inch of bit diameter is closely related to bit life. A 6-3/4-inch tricone rock bit has almost twice as much bearing-surface area as a 4-1/2-inch bit (3, p. 152). A hard-formation bit of a given size should have a larger bearing area than a soft-formation bit of the same size.

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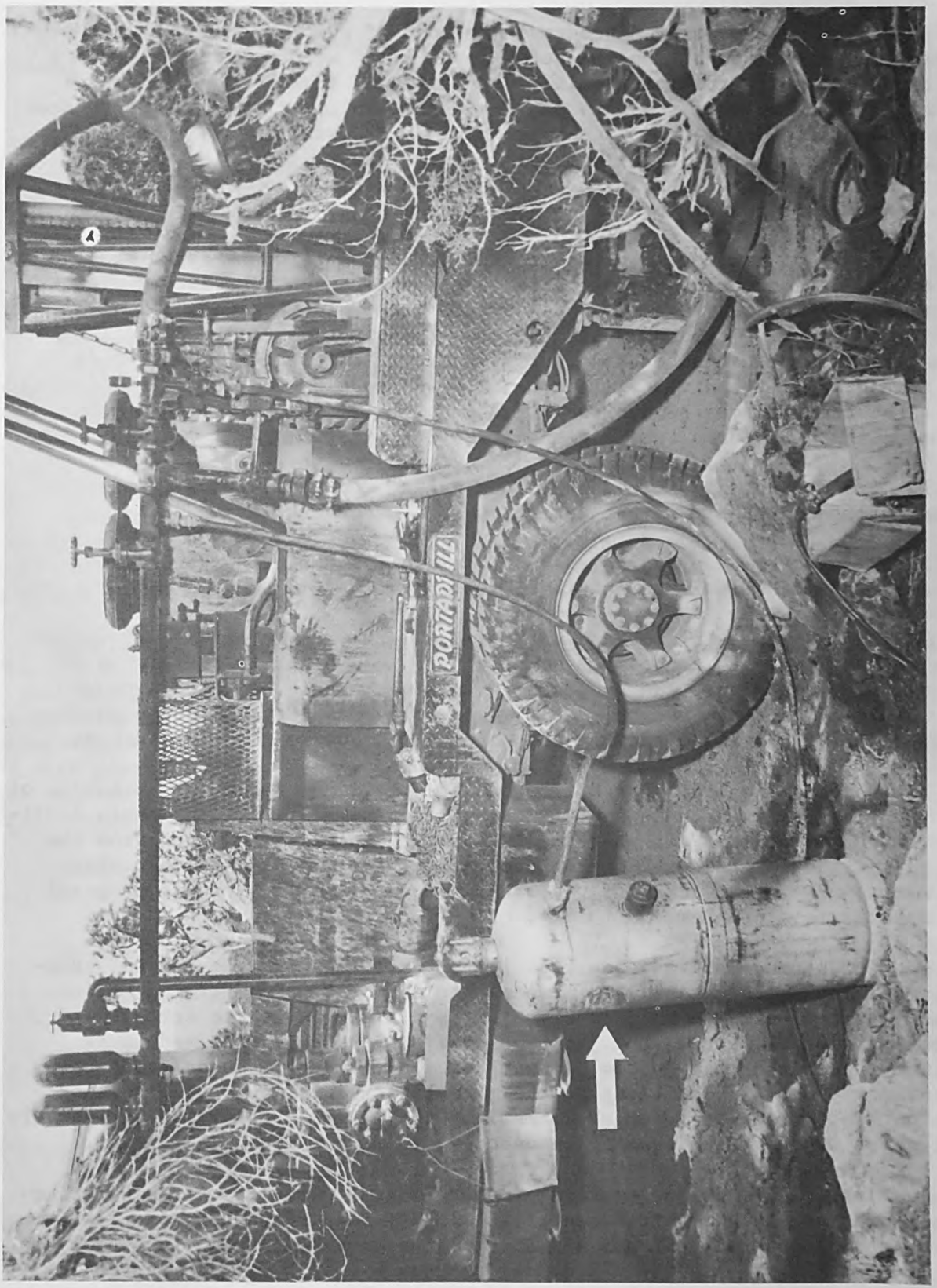

FIGURE 4. - Liquid Petroleum Gas Container (Arrow) Adapted for Use as Water Tank for Water Injector.

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rock bit of the two-cone type, designed for use in small holes, has the advantage of large cones with proportionately greater structural strength in cutters and bearings. With air as a drilling medium, the bit pressure is only about one-half that required with water or mud medium; also, the rate of rotation usually ranges from one-half to three-fourths that needed with water or mud medium (16, p. 114).

The accuracy of samples obtained from dry cuttings is largely dependent upon ground conditions and the efficiency of the sample-collection system. Assuming satisfactory ground conditions, sampling accuracy depends primarily on how the cuttings are collected at the surface. The cuttings may be caught by a specially constructed device, or by a combination of such devices. The simplest method of obtaining samples is to allow cuttings to accumulate in a pile at the hole collar. This method, however, often involves excessive dust loss.

The cone-type collector (fig. 5) or a comparable box-type collector constitutes what may be considered a standard sample catcher. Small quantities of moisture in the cuttings may affect sample accuracy (moist cuttings tend to accumulate on the collector walls) and may plug the system. The umbrella-and-split-pan collector system (fig. 6) is easily operated and will not become plugged if moisture is encountered. Tandem arrangement of box-type and cone-type collectors, illustrated in figure 7, should provide a sample of relatively high accuracy. Samples of dry cuttings, although not completely reliable, are generally more dependable than samples of wet cuttings obtained in noncore drilling that utilizes mud or water medium.

The technique for identification of strata by examination of dry cuttings is gradually being improved. Dry particles should be just as amenable to identification as the particles produced from drilling with a liquid medium.

Compressed Air Requirements

For best results in rock-bit drilling with compressed-air medium, primary attention must be given to pressure and volume requirements.

In determining compressor-pressure requirements, basic considerations include depth of drilling and anticipated water conditions. Rotary blowers capable of producing relatively large volumes of air, 500 to 600 c.f.m. at pressures of 35 p.s.i. or less, are quite satisfactory in dry formations, to a depth of about 700 feet. Higher pressure is necessary in deeper holes or if water is encountered.

According to Magner (15, p. 116), a pressure of 100 p.s.i. was adequate for cleaning an extremely wet hole to a depth of 400 feet if volumetric requirements were also met. Air compressed to 200 p.s.i. was required for successful drilling under similar hole conditions at a depth of 700 feet. The height of the water column is not known for that particular drilling, but the hydrostatic head probably did not exceed 230 feet in the 400-foot hole, nor 462 feet in the 700-foot hole. The minimum air pressure required to displace a column of water from a hole can be calculated from the following formula:

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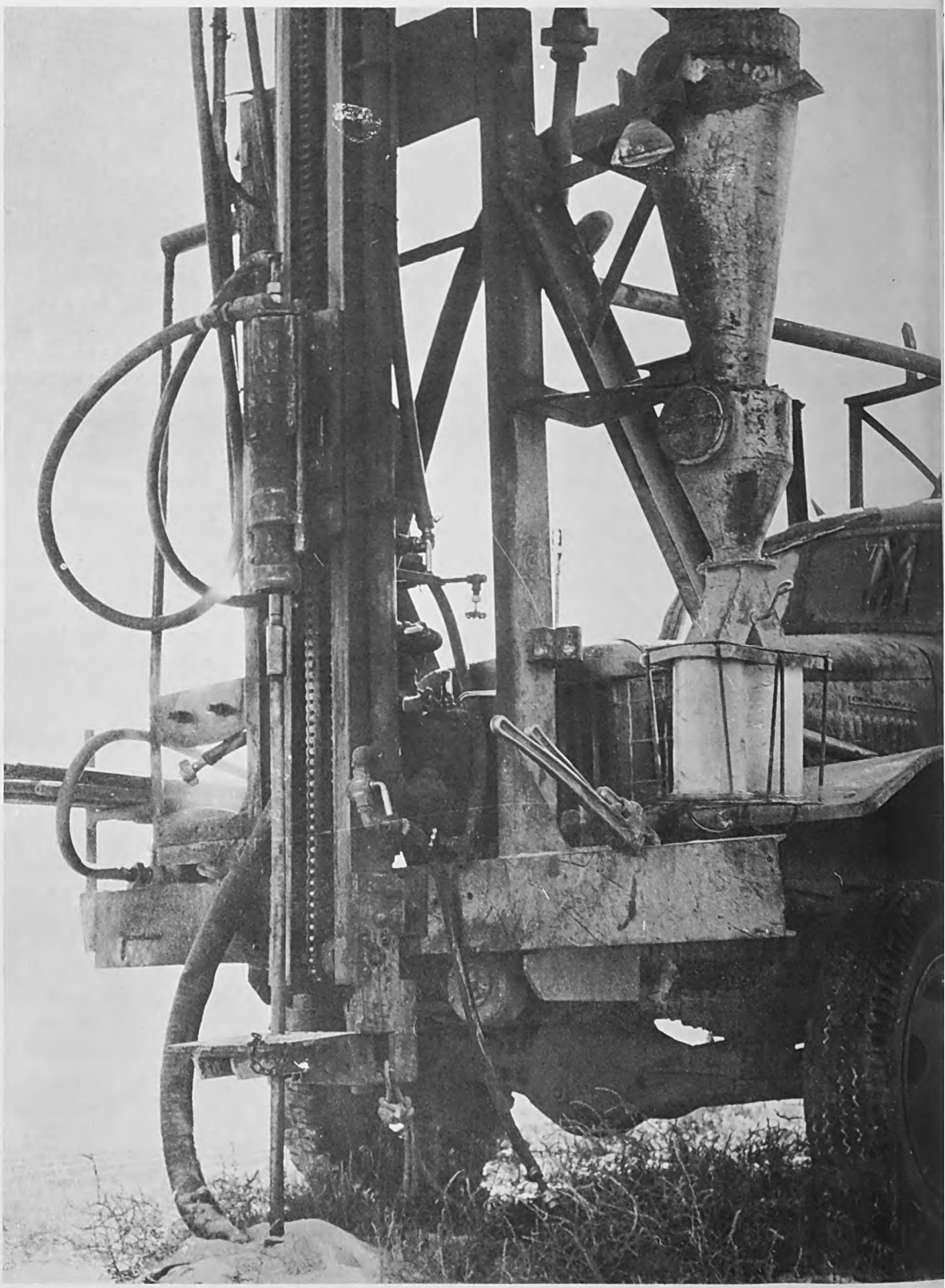

FIGURE 5. - Ducon Dust Collector Used to Trap Drill Cutting and Dust From a Pneumatic-Percussive Drill. *(Courtesy of Lippoth and Wein Drilling Co.)*

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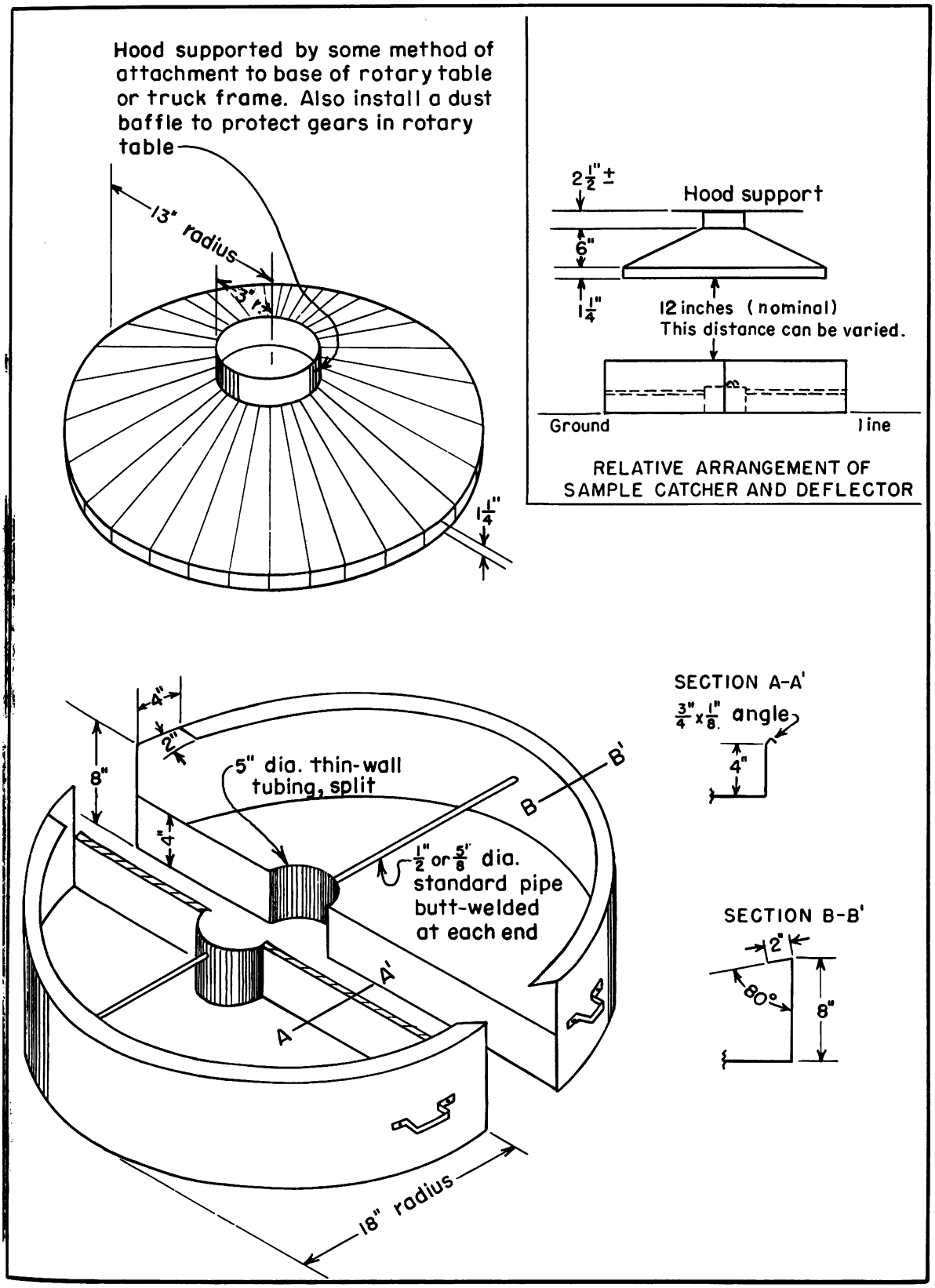

FIGURE 6. - Sample Catcher Used With Rotary-Table Drill Rigs. Deflector Is Similar to Winter-Weiss Dust Hood. *(Courtesy of Teton Exploration Co.)*

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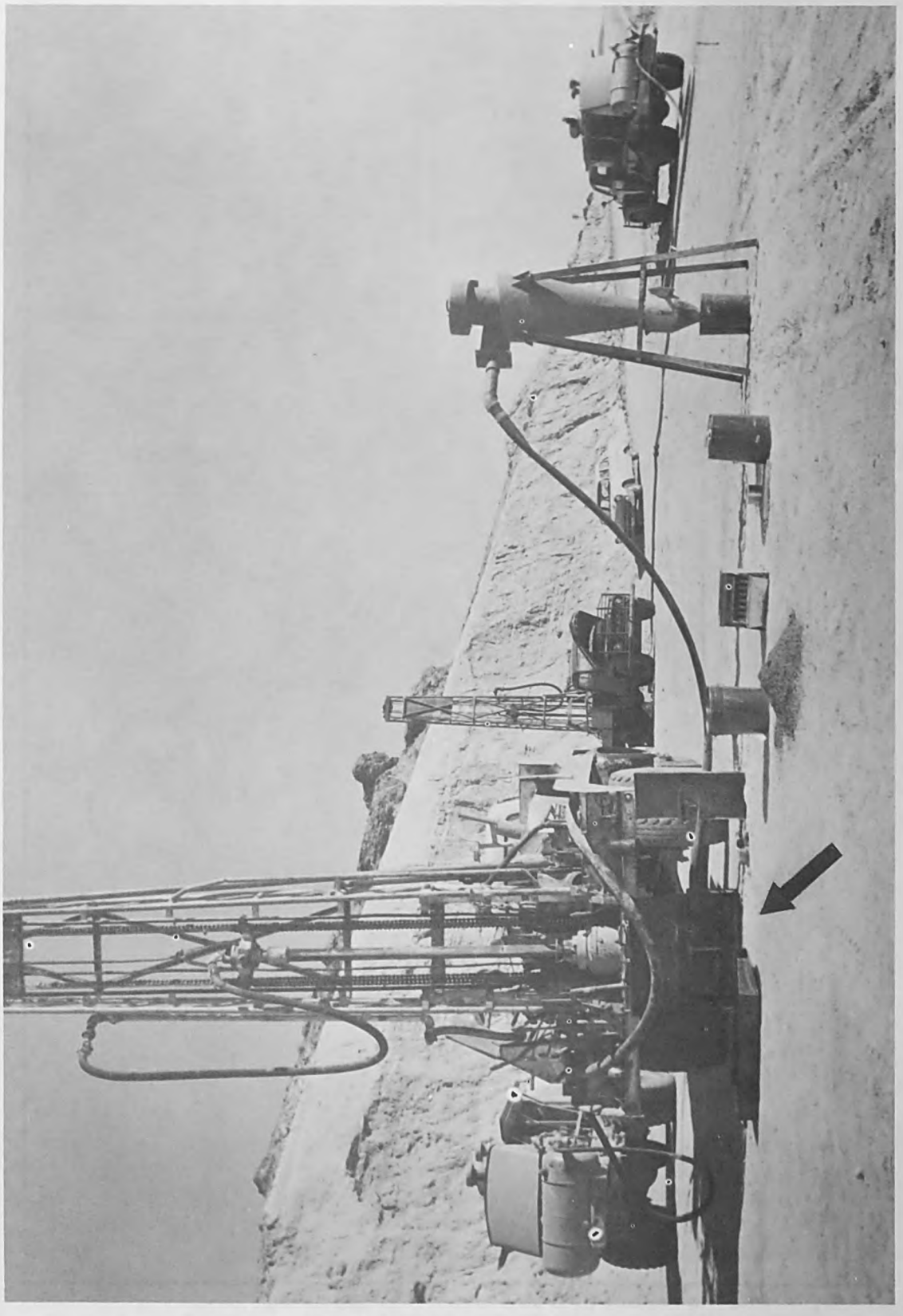

FIGURE 7. - Tandem Arrangement of a Lucky Mc Box-Type Dust Collector (Arrow) and a Cone-Type Collector.

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$$P = 0.433\ H$$

Where: P = pressure in p.s.i.

H = vertical height of water column in feet

Obviously, after displacement of the water from a hole, the air pressure can be reduced. A balance will then be established dependent upon the compressor capacity, size and length of drill pipe, constrictions in the system, and back-pressure caused by the weight of the suspended solids and water above the bit. If the compressor does not unload while drilling progresses, it is delivering at least its rated capacity of air.

Ground water that seeps into a deep hole during a drill shutdown period can be blown out in stages as the drill rods are lowered into the hole, and an air pressure of 100 p.s.i. will normally be adequate for this purpose. However, elimination of a large volume of water, from a flow that can fill a hole during the time taken to add a section of drill pipe, will require higher pressure air. When the available pressure is inadequate to lift the water, an alternate introduction into the drill pipe of compressed air from the compressor and water from the mud pump may clear the hole. In this method, compressed air is admitted into the drill pipe and is then forced down the drill pipe by the water from the mud pump. The water column formed inside the drill pipe tends to counterbalance the water column in the annulus while more compressed air is admitted into the drill pipe. In this manner, the water in the annulus may be discharged. The available air pressure may then be adequate to resume drilling. Air discharged at the bit returns to the atmosphere through the annulus (normal-flow system) or through fractures in the formation. Assuming no loss of air to the formation, the velocity at which the air passes to the hole collar is determined by the volume of air discharged at the bit and the area of the annulus. The average velocity in the annulus can be computed from the following formula:

$$V = \frac{144\ Q}{A}$$

Where: V = velocity, f.p.m.

Q = input air volume, c.f.m.

A = area of annulus, sq. in.

The terminal velocity of particles in free-fall in still air can be calculated from a mathematical expression of Newton's law. The terminal velocity of a particle is equivalent to the required critical velocity of flushing air that will just support the particle in the rising column of air in a vertical drill hole. The computation is correct for spherical particles under ideal conditions. In drilling with air medium, the particles in the airstream are of various sizes, shapes and, perhaps, densities; therefore, each particle has a different terminal velocity in the air medium. The particles are crushed and broken in the turbulent airstream and by grinding action between the drill pipe and the wall of a hole. Few of the larger chips formed by a

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rock bit are spherical; so a more accurate terminal velocity may be computed if the Newton equation is modified to include the effect of nonspherical shapes and of the fluid density of the air-solids mixture.

Much experimental work pertaining to air-volume requirements has been done by petroleum companies and equipment manufacturers. Under the conditions prevailing during these experiments, the required annular velocities ranged from 2,000 to 4,000 f.p.m. (1, p. 325).

Dr. H. L. Hartman[6/] did experimental work on pneumatic conveying of drill cuttings (10) and developed a relatively simple graphic method for determining air-volume requirements for drilling with air medium (9, p. 82). Based on formulae presented in Dr. Hartman's article, a graph was constructed for determining air-volume requirements in holes to 7 inches in diameter (fig. 8). Quadrants 1 and 2 of the graph apply to rock with a specific weight of 165 pounds per cubic foot (sp. gr. 2.64). Quadrant 3 illustrates critical velocities for particles of various diameters. The critical velocities are computed from the following modification of Newton's equation (9, p. 81).

$$V = 2.56\sqrt{d\, w_{s/w}}$$

Where: V = critical air velocity, f.p.s.

d = particle size, in.

w_s = specific weight of rock, lb. per cu. ft.

w = specific weight of air-solids mix, lb. per cu. ft., which is determined by adding the specific weight of standard air (0.072 lb. per cu. ft.) and the solids load in lb. per cu. ft. of air.

Correct determination of the required volume of air coincidentally solves the weight of cuttings, the solids load, and the critical air velocity.

Reliability of the chart is determined by accuracy of assumptions pertaining to prevailing drilling conditions; in any event, the required quantity of air indicated by the graph should be considered as a minimum. In this regard, it should be pointed out that air velocities below 2,000 f.p.m. are in a sensitive range regarding slight changes in conditions.

Use of Air Medium in Core Drilling

For several years, compressed air has been used in diamond drilling for bit cooling and cuttings removal. This technique is now common practice. In softer rocks, the heat generated at the cutting face of the bit can usually be adequately dissipated with air medium. In dense or glassy rocks such as unaltered granite, quartz, quartzite, chert, and jasper, dissipation of heat

6/ Hartman, H. L., Head of Dept. of Mines, Pa. State University.

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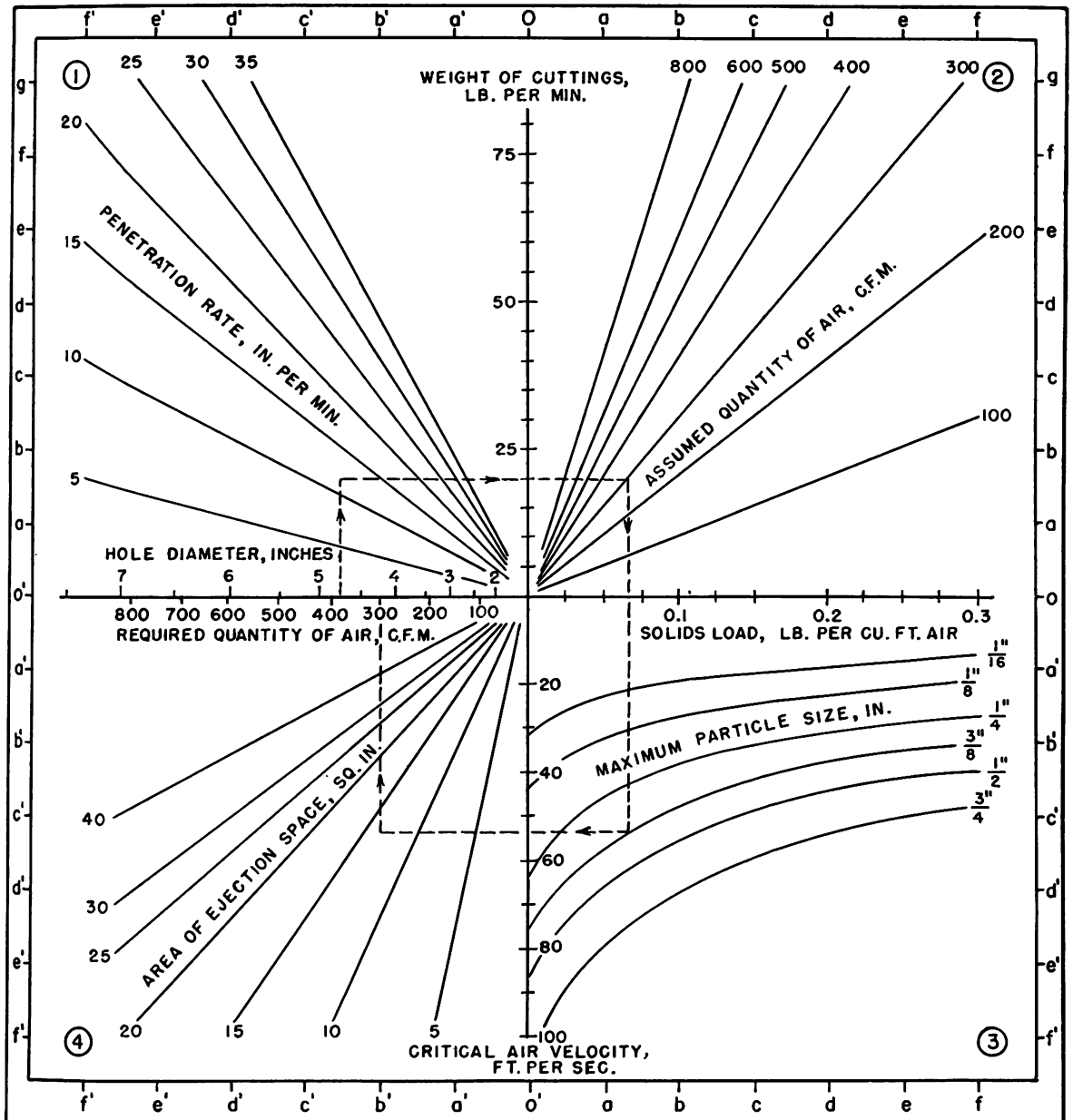
WEIGHT OF CUTTINGS, LB. PER MIN.
PENETRATION RATE, IN. PER MIN.
ASSUMED QUANTITY OF AIR, C.F.M.
HOLE DIAMETER, INCHES
REQUIRED QUANTITY OF AIR, C.F.M.
SOLIDS LOAD, LB. PER CU. FT. AIR
AREA OF EJECTION SPACE, SQ. IN.
MAXIMUM PARTICLE SIZE, IN.
CRITICAL AIR VELOCITY, FT. PER SEC.

Use table below to compute ejection area. Subtract area of drill rod from area of hole when considering a normal flow system

Cross-section area, sq. in.

DIAMETER (N)	1-INCH	2-INCH	3-INCH	4-INCH	5-INCH	6-INCH	7-INCH
N	0.79	3.14	7.07	12.57	19.64	28.27	38.48
N + 1/4"	0.99	3.98	8.30	14.19	21.65	30.68	41.28
N + 1/2"	1.77	4.91	9.62	15.90	23.76	33.18	44.18
N + 3/4"	2.41	5.94	11.04	17.72	25.97	35.78	47.17

FIGURE 8. - Graph for Solution of Air-Volume Requirements for Noncore Drilling.

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ordinarily cannot be satisfactorily accomplished by compressed air. The effect of compressed air as a cooling medium in drilling is enhanced by adding small quantities of water. The quantity of water should be varied to suit the drilling conditions. Excess water in the compressed air can be detrimental. Most of the techniques used in noncore drilling to overcome difficulties arising from hole constrictions, caving ground, and fractured formations are applicable to core drilling.

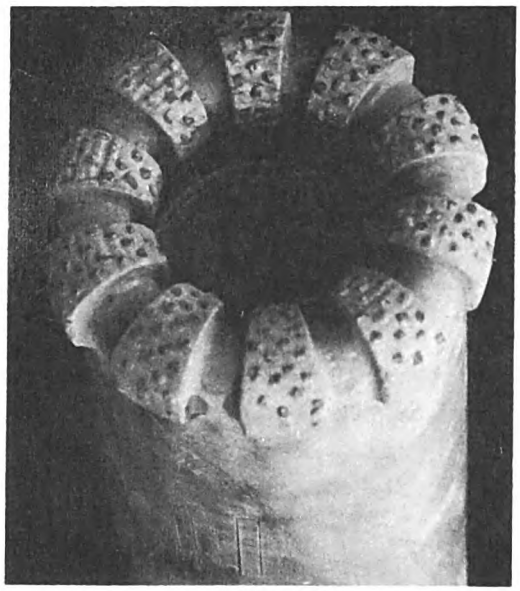

FIGURE 9. - Typical Diamond Bit (4-1/2- by 1-7/8-Inch) for Use With Air Medium. Note Large Discharge Courses.

If proper procedures are followed, compressed air can be a satisfactory medium in wet holes. The hole should be cleared of surplus water, or the water thoroughly aerated, before coring is begun. After the surplus water is removed or aerated, the air medium will prevent a buildup of water at the point of penetration during the coring operation. For most effective results with compressed-air medium, discharge courses in the diamond bit should be large and/or numerous (fig. 9) to permit maximum airflow past the bit. Very light or moderate pressure, adequate to prevent bit chatter, is maintained on the bit. In dry holes, rattle of the drill rods might be interpreted as bit chatter; however, an experienced driller can sense the difference. Moderate rod rattle is apparently not detrimental to the equipment or to core recovery.

Core drilling with diamond bits and utilizing compressed air medium are generally applicable in shale, mudstone, siltstone, sandstone, water-soluble minerals, or in formations easily eroded by water medium.

The graph shown in figure 8 cannot be used to compute air-volume requirements for diamond-core drilling. The critical velocities would be satisfactory for cuttings removal, but the correspondingly low volume of air would not cool the diamond bit.

An adequate supply of compressed air at a suitable pressure, and with properly designed drill tools in the hands of experienced drillers, are primary requirements for successful core drilling with diamond bits cooled by air.

Practice at Beaver Mesa

In May 1958, R. J. Colquitt, drilling contractor, was using the compressed-air flushing method when drilling core and noncore holes for New Idria Mining & Chemical Corp. The holes were drilled on Beaver Mesa, southwest of Gateway, Colo., to explore for uranium in the Jurassic Morrison formation. Average hole depth was 458 feet, of which about 75 feet were core drilled.

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The drill rig and auxiliary equipment consisted of a Portadrill 1500 chain-feed unit, mounted on an R-190-Series International Harvester 2-wheel-drive truck, with gasoline-powered engine. Drill rods were 2-3/8-inch external upset exploration pipe in 10-foot lengths. The 15-foot core barrel was a swivel-type, double-tube unit, 3-1/2-inch O.D., manufactured by Christensen Diamond Products Co. The 10-waterway, 4-1/2- by 1-7/8-inch bit was set with 4-per-carat-size diamonds (fig. 9). A Gardner-Denver-600, rotary-type compressor, rated at 600 c.f.m. at 100 p.s.i. was used in all drilling.

Noncore drilling with a 4-3/4-inch roller-type rock bit proceeded normally until the return air was lost at a depth of 120 feet. After drilling a few feet beyond that point the compressor outlet pressure increased to about 60 p.s.i. from the normal 50 p.s.i. indicating a mud collar or constriction in the hole. The water injector was out of order, so the driller added about 5 gallons of water through the drill rods, at 5-foot intervals, in an attempt to soften the mud collar. The penetration rate was reduced by decreasing the feed pressure and the rotation rate to about 80 r.p.m. No cuttings or dust were discharged from the hole collar after air circulation was lost at 120 feet. The air and cuttings were discharged into fractures in the formation. This was indicated by failure of the compressor to unload during drilling and by the ease with which the drill rods turned when lifted slightly off the bottom. Noncore drilling was stopped at 280 feet, and the tools were pulled to within 125 feet of the collar, where they stuck tightly. The driller had expected the bit to hang up near the place where air circulation was lost. Considerable water was added to the hole outside the drill rods to saturate and soften the mud collar, and after much effort the tools were extracted. The driller was confident that the mud collar would not have caused difficulty had the injector been used as soon as circulation was lost. The hole was then reamed with a rock bit, and much muddy water was discharged from the hole.

Coring was started in red mudstone at 280 feet. A mud slurry was discharged from the hole when coring began and periodically thereafter. Compressor outlet pressure was 75 to 80 p.s.i., and a discharge of air was noted at the hole collar as core drilling progressed. Rotation rate was about 60 r.p.m. while coring, and the pulldown chains were snug. Including the time taken to add one 10-foot section of drill pipe, 15 feet of core was cut in 36 minutes. The strata were variegated mudstone and coarse-grained sandstone. Core recovery for the job total of 320 feet of coring was very nearly 100 percent.

Using a 15-foot core barrel and beginning at a 300-foot depth, the driller estimated the normal coring rate at about 70 feet in 4 hours. The 4-1/2 by 1-7/8-inch bits were used for core drilling about 600 feet before they were removed from service. Salvage value ranged from 50 to 60 percent. The contractor believed that using a worn bit was expensive because of excessive diamond loss and decreased drilling rate.

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Practice at Buckskin Mountain

A drill rig, owned and operated by R. Scott, of Moab, Utah, was used for exploratory drilling on property belonging to Anschutz Drilling Co. on the west slope of Buckskin Mountain. The property is at the head of Salt Creek, in San Juan County, Utah. Holes were started in the Chinle formation and were drilled through the Mossback formation into the Moenkopi formation. All these formations are of Triassic age.

The drill rig, (fig. 10) originally a truck-mounted wagon drill, can be used for drilling holes with either rotary-drilling equipment or pneumatic-percussive equipment. The holes on the Anschutz property were drilled with the rotary equipment. The 22-foot drill mast, constructed of two parallel pieces of 5-inch channel iron placed 8 inches apart, was hinged on a heavy inverted U-frame on the front end of a Model 969, 6-wheel-drive, 4-ton-capacity Diamond T truck. The mast can be laid back over the truck cab when the drill rig is to be moved.

The air compressor, a Gardner-Denver model WHK 2001, rated at 500 c.f.m. at 100 p.s.i., was driven by a D-13000 Caterpillar engine. The compressor was mounted at the rear of the truck. The two pieces of channel iron that formed the mast also served as guides for a slideplate to which was fastened a 15-hp., 5-cyl., radial-type, air-driven Gardner-Denver model MMGP drilling motor (fig. 10). The slideplate was pulled up or down with a No. 80 roller chain that engaged an 11-tooth sprocket wheel turned by a 2-1/2-hp., 5-cyl., radial, air-driven Gardner-Denver MA3 hoist motor.

A pneumatic-percussive deep-hole drill was provided as auxiliary equipment. The rotary-drilling motor can be removed by unscrewing four stud bolts, and the deep-hole drill can then be put in its place on the slideplate. Because the centerlines of the machines are at different distances from the slideplate, the entire drill rig must be moved forward about 5-1/4 inches to aline the deep-hole percussive drill with a rotary-drilled hole.

When drilling with the deep-hole drill, 2-1/4-inch-diameter bits with extended-wing carbide inserts were used with 18-foot lengths of 1-1/8-inch sectional long-hole rods.

Rotary equipment included flush-coupled A rods and K-type, 2-15/16-inch tri-cone rock bits. Compressed air for blowing out cuttings was introduced into the drill rods through an air swivel placed nust below the drill motor (fig. 10). Samples of the cuttings were caught in a modified No. 2 Ducon dust collector.

The rate and direction of rotation of the drill motor were controlled easily by a three-way air valve. This facilitated breaking the threaded rod connections when adding or removing drill rods. The average time taken to add a 10-foot section of drill rod was 23 seconds. The total time required to change the bit and resume drilling at a depth of 120 feet was 14 minutes. The maximum drilling depth by the rotary method was reported to be 400 feet. At greater depth the rig lacked the necessary hoisting capacity.

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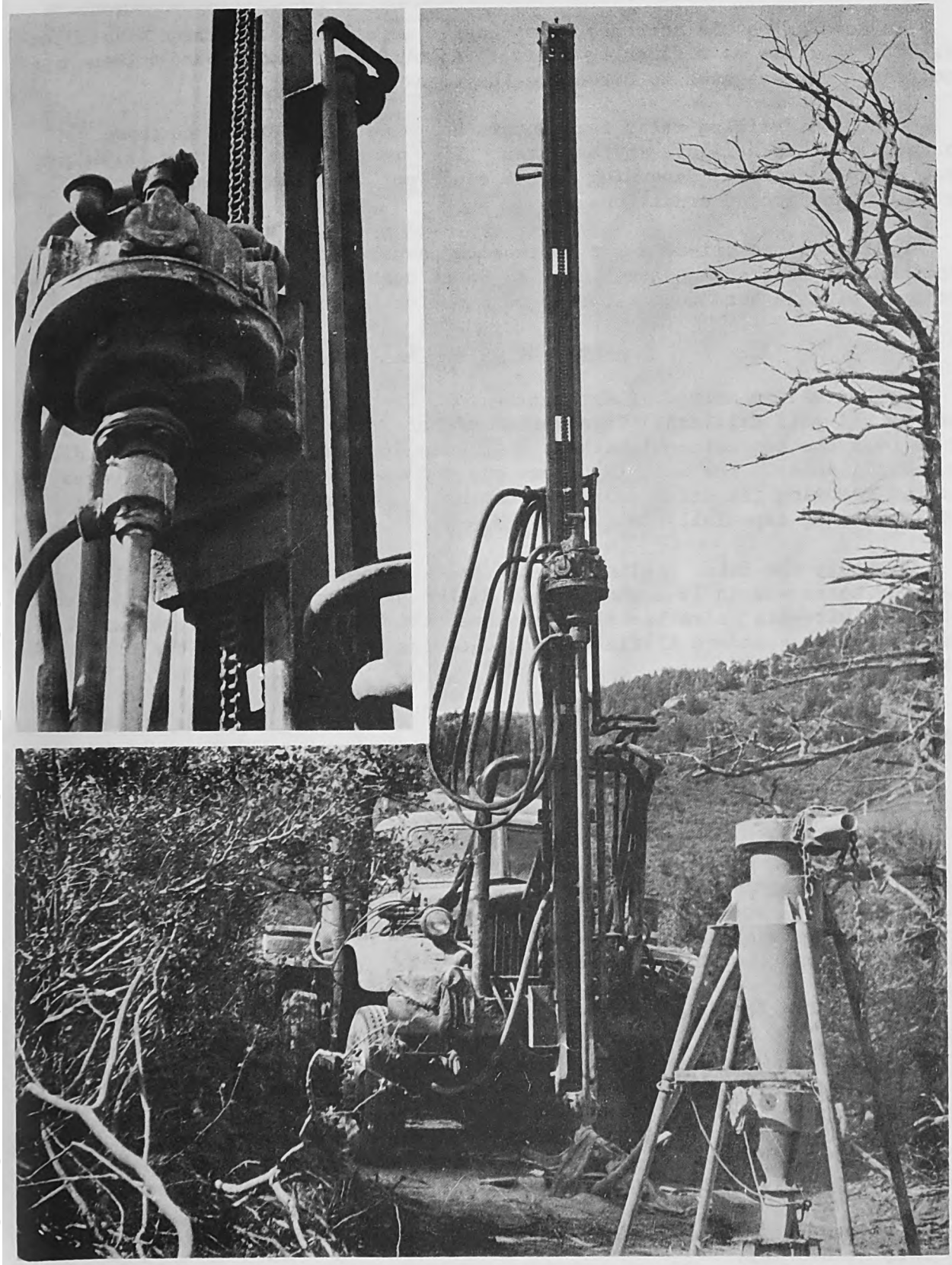

FIGURE 10. - Truck-Mounted Wagon-Drill Rig With Air-Powered Rotary-Drill Motor in Place of Pneumatic-Percussive Rock Drill. Inset Shows Closeup of the Drill Motor.

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In some holes the presence of excessive moisture necessitated substituting water for air as a flushing medium. A horizontal duplex pump driven by compressed air was used to circulate the water.

Contract drilling rates for noncore holes were comparable to those charged by other drillers in that area. They ranged from $0.75 to $1.50 per foot of hole drilled, depending on the equipment used, depth and amount of drilling, and ground conditions.

Retipping the tri-cone bit teeth with powdered tungsten carbide in a steel matrix is a common practice. R. Scott considers the performance of the retipped bits in hard formations to be superior to that of new bits.

Wire-Line Core Drilling

The wire-line method of extracting core from core-drill holes first was used by oil-well drillers. This method of core removal had a number of advantages over the conventional methods used when drilling smaller diameter diamond-drill holes. The most important one was that core could be recovered without removing the drill rods from the hole, thus greatly reducing lost drilling time, especially in deep holes.

Probably the first application of the wire-line technique to small-diameter holes was in 1946 when the E. J. Longyear Company built and tested a BX-size wire-line core barrel in southwestern Virginia. The core barrel was adapted to standard AX flush-coupled casing which served as the drill-rod string.

Wire-line equipment for drilling with a diamond bit consists of the following items:

1. An outer tube assembly, with reaming shell and coring bit, that is fastened to specially designed drilling rods.

2. An inner tube assembly consisting of a core-holding tube, core lifter, ball-bearing swivel head, locking head and spear.

3. An overshot device, attached to the end of the wire line (hoisting cable) to engage the inner tube assembly.

4. A hoist for raising or lowering the inner tube assembly through the drill rods.

See figure 11 for wire-line, core-barrel nomenclature.

A water shutoff device, consisting of a rubber washer, is usually a part of the inner tube assembly. Its use is recommended when pumping in closed circuit (no bypass in the line). The washer is squeezed against the outer tube when a core block results in pressing the inner tube against the washer. The consequent pressure increase, as shown on the pump gage, indicates that the core is blocked.

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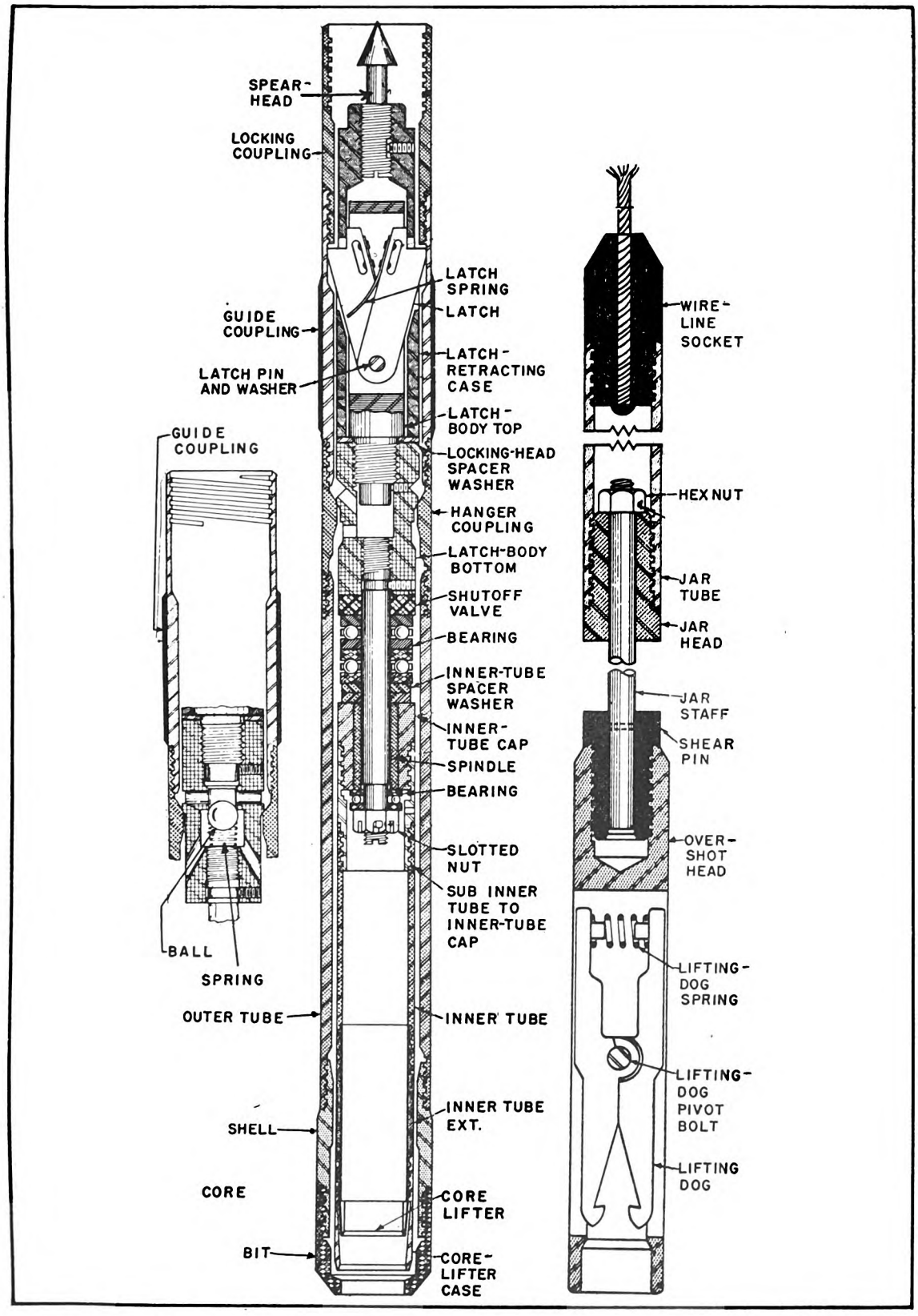

FIGURE 11. - Nomenclature of Wire-Line Core Barrel and Overshot Assembly.

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Wire-line equipment can be used in standard-size diamond-drill holes. The wire-line core recovered from a standard-size hole is 1/16 inch smaller than the core of the next smaller standard size. For example, the wire-line core from an NX hole is 1-9/16 inches in diameter, whereas the standard BX core is 1-5/8 inches in diameter.

TABLE 5. - E. J. Longyear wire-line core-barrel specifications

Set reaming shell		Set bit		Hole diameter, inches	Core diameter, inches
Size	O.D. inches	O.D. inches	I.D. inches		
AXWL.....	1-57/64	1-55/64	3/4	1-29/32	3/4
BXWL.....	2-23/64	2-11/32	1-1/8	2-3/8	1-1/8
NXWL.....	2-63/64	2-61/64	1-9/16	3	1-9/16

The inner barrel, when dropped in a vertical or nearly vertical hole, will fall through water at a rate of about 200 feet per minute. A distinct shock is transmitted through the drill rods when the core barrel seats itself.

The inner barrel may be forced into position by pumping if the hole is not vertical, or is more than 1,000 feet deep, or when using a relatively heavy mud fluid. In closed-circuit pumping, the fluid pressure increases sharply when the barrel is seated.

Operation of Wire-Line Equipment

When the wire-line coring bit, outer tube assembly, and wire-line drill rods are in drilling position in a hole, the inner tube assembly is dropped into place and drilling proceeds in much the same manner as when conventional equipment is used. If the hole is dry, or the water is more than 100 feet below the hole collar, the inner tube assembly is attached to the overshot device, which is equipped with a dry-hole overshot release, and is then lowered into position.

After the desired amount of core has been cut, or after drilling is stopped for any other reason, the drill bit should be raised slightly off bottom, and the hole should be flushed while the drill rods are rotated. The bit should then be lifted a foot off bottom, or more, if necessary to place the top joint above the footclamp and in a convenient position for "breaking". Heavy material and drill cuttings not removed from the hole settle to the bottom when circulation is stopped. If the bit is not clear of the settling region, the heavy material can enter the outer tube and prevent proper seating of the inner tube assembly, or interfere with subsequent circulation of drill fluid. When the drill rods are cleared, the overshot is lowered through the drill rods, and the lifting dogs of the overshot device are hooked onto the spear of the inner tube assembly. The latches that lock the inner tube assembly in position retract when the wire line is pulled up, and the core-laden inner tube can then be hoisted to the surface through the drill rods (fig. 12).

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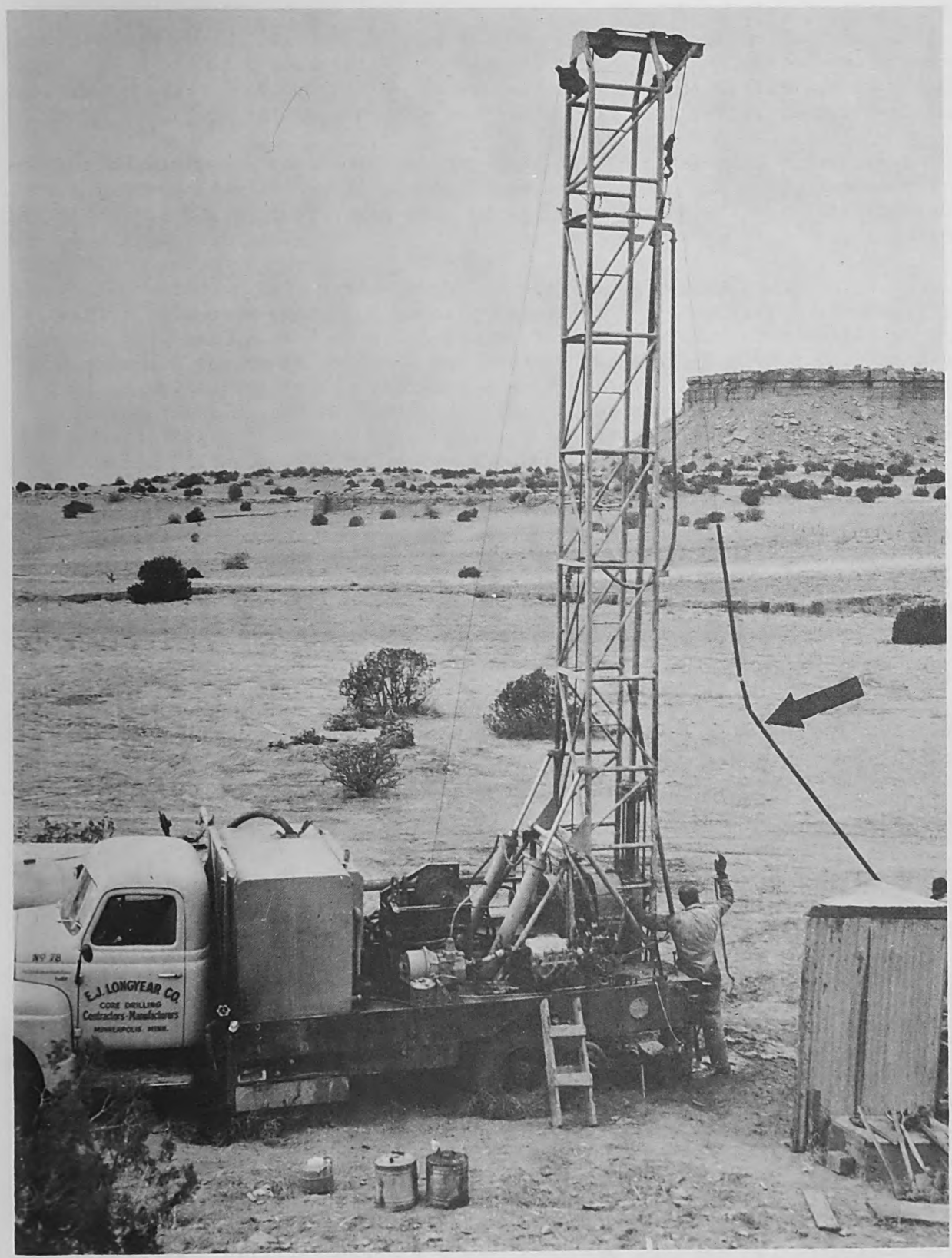

FIGURE 12. - Wire-Line Inner Tube Assembly (Arrow) Removed From Hole. Note Sharp Bend Where Overshot Connects to Spearhead of Inner Tube Assembly. E. J. Longyear Co. Rig. Jackpile Mine Property, Grants District, N. Mex.

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As soon as the inner tube assembly is out of the drill rods, a duplicate assembly may be dropped or lowered through the drill rods into the hole (fig. 13). When the replacement assembly is seated, drilling can be resumed while core is being extracted from the inner tube assembly at the surface.

A desirable unit for use with wire-line equipment is a positive-displacement pump with separate motor and transmission. Closed-circuit pumping is necessary if the drill operator relies on pump-gage pressure for indication of core blocks or loss of circulating medium.

With the inner tube removed from the core barrel, the unobstructed opening from hole collar to bit facilitates placement of high-viscosity drill mud, or filler materials such as cottonseed hulls or bran. Cementing through the wire-line rods and the outer tube of the core barrel is not recommended practice unless the drill crew is highly skilled. Hole-inclination tests can be made by lowering a clinometer through the wire-line drill rods, thereby saving time and expense. Experiments are being conducted to perfect a method of extracting the inner tube from holes inclined at less than 35° below the horizontal. The inner tube can be pumped into place in holes of low-angle inclination, but placement of the overshot presents a difficult problem. Wire-line equipment, as previously described, can be used wherever conventional diamond drilling is done in holes inclined more than 35° below the horizontal. Bit life and hole depth must be such that the initial cost of additional equipment is justified. No distinct advantage is indicated if drilling conditions necessitate changing the bit at frequent intervals, or if hole depth is less than 100 feet.

A wire-line bit is more expensive than a conventional bit of similar diameter, but the higher initial cost is usually offset by a relatively greater salvage value. Diamond cost per foot drilled is usually about the same for wire-line diamond drilling as it is for conventional diamond drilling.

Practice at Hauber Property

An E. J. Longyear wire-line core barrel was used by contractor L. Materi in a drilling project for the Homestake Mining Co. at the Hauber property in Crook County, Wyo. Some preliminary drilling had already been done on an irregular, 400- to 500-foot grid by the Atomic Energy Commission in 1954. The Homestake holes were drilled noncore through the Skull Creek shale, and the sandstone, mudstone, and siltstone members of the Fall River formation, to depths of 220 to 347 feet. The holes were then completed by core drilling. When drill-hole data could not be satisfactorily correlated, intermediate holes were drilled.

The interval cored in the well-consolidated sediments ranged from 7 to 58 feet. One hole was core drilled with wire-line equipment from the surface to a completion depth of 367 feet.

A Mayhew 1000, truck-mounted drill rig, equipped with a Gardner Denver 5- by 6-inch duplex mud pump was used in the noncore drilling. Because of the high water table, all noncore holes were drilled wet. Commercially

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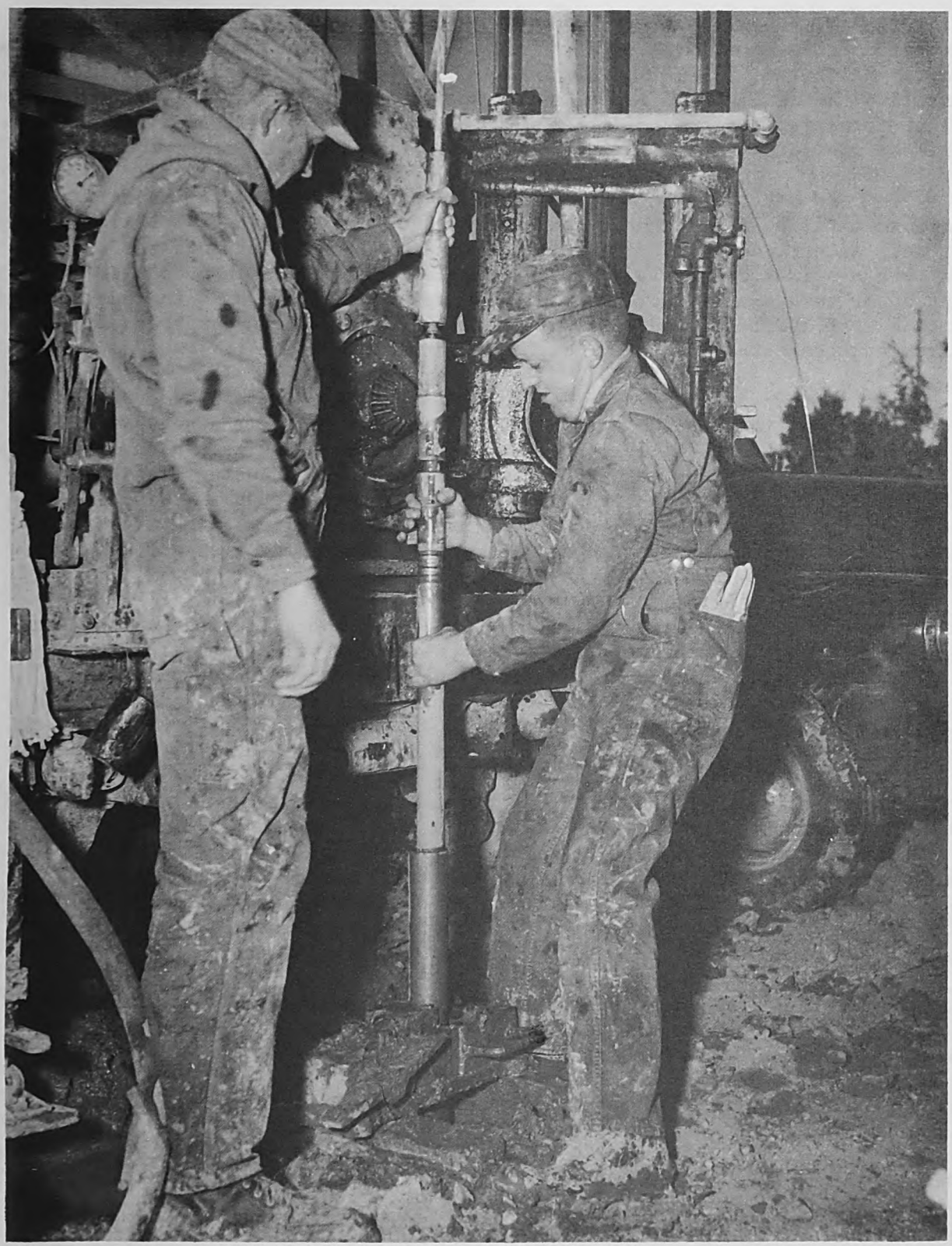

FIGURE 13. - Dropping NX Wire-Line Inner Tube Assembly. Note Spearhead Emerging From Overshot Assembly. L. Materi Drill Rig. Hauber Property, Crook County, Wyo.

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prepared drilling mud was added to the water medium only when circulation was lost. Hawthorne, 4-3/4-inch-diameter, drag-type insert bits were used for drilling the Skull Creek shale and the sandstones and siltstones of the Fall River formation. Normally, one new drag-type bit was sufficient for one hole. Tricone rock bits were used for noncore drilling through harder rock strata.

The ore-bearing stratum is quite flat lying so the approximate depth of noncore drilling in each hole can be computed from known hole-collar elevations. After each 5 feet of drilling, a sample of the cuttings was caught on a hand-held screen. The cuttings samples were placed in proper sequence and later were examined by the field geologist. Noncore drilling was stopped 3 to 5 feet above the ore-bearing strata. Casing, which consisted of 3-inch-diameter steel pipe, was then placed in the hole.

The noncored portion of a hole could be drilled in less time than the cored portion; this caused an excessive loss of time for the noncore-drill-rig crew. Much core-drill-rig time was lost in clearing core blocks caused by thin mudstone layers interbedded with sandstone. By using wire-line equipment, the drill operator could core-drill fast enough to complete one hole by the time another hole was ready for core-drilling. The time taken to pull casing, move, and then set the core-drilling rig over a previously-cased hole ranged from 1-1/2 to 2-1/2 hours.

The core-drilling rig was a Longyear UGN 24 hydraulic-feed unit. The drill-head power source was a gasoline-powered, 6-cyl. Wakesha industrial engine. The drill unit, with a hydraulically operated 29-foot mast and a belt-driven Bethlehem 4- by 6-inch duplex mud pump with 3-inch liners, was mounted on a 1941 model HS, FWD chassis. The wire-line hoist, with hydraulic motor, was mounted on the truck bed to the right of the drill-head engine.

The NX-size wire-line coring bit, outer tube assembly and wire-line drill rods were lowered into the drillhole until stopped by loose material near the bottom. The mud pump was then started, and with drill rods rotating, water was circulated until the hole was clean. Normal cleanout time was reported to be 10 or 15 minutes. Coarse drill cuttings or loose gravel in the drill hole increased the cleanout time because the clearance between the drill rods and the inside of the casing was only one-eighth-inch.

After the hole was washed clean and the wire-line drill rod was cleared before inserting the inner tube assembly, a time check to the nearest 5 seconds was kept, as shown in table 6.

For drilling in mudstone, the weight of the drill rods and core barrel provided sufficient bit pressure. For drilling in sandstone, a hydraulic-feed gage pressure of about 200 p.s.i. was maintained, in addition to the weight of the rods and core barrel. The chuck was rotated at 200 r.p.m. Circulating-pump gage pressure was 200 to 250 p.s.i. when drilling for core in either mudstone or sandstone.

The diamond bit used for coring was designed for drilling in coarse-grained sandstone, so the penetration rate in fine-grained mudstone was

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considerably reduced, as indicated by the time required to core drill the first 2 feet of ground (table 6). According to the drill operator, the use of wire-line equipment reduced the occurrence of core blocks; the wire-line diamond bit seemed to be suited for drilling in sandstone interbedded with thin layers of mudstone.

The contractor tried to core-drill through a 4-3/4-inch-diameter hole without first casing it, but the drill rods whipped, and the seals at the rod joints were damaged. Considerable time was lost in connecting and disconnecting the four-thread joints.7/

The exploration-drilling program had not been completed, but the comparative core-recovery data shown in tables 7 and 8 were available.

TABLE 6. - Time check, core drilling with wire-line equipment, Hauber property, Wyo., 1957

Drill-hole depth, feet	Action	Elapsed time, min.	Elapsed time, sec.
297	Drop inner barrel		
	Inner barrel seated	1	20
	Start drilling	1	25
299	Rechuck	22	15
	Start drilling	0	35
301	Rechuck	1	30
	Start drilling	0	35
303	Rechuck	1	30
	Start drilling	0	35
305	Stop drilling	2	55
	Drop overshot	2	50
	Overshot seated	1	10
	Inner barrel at surface	1	20
	Remove core		
	Drop inner barrel	7	40
305	Inner barrel seated	1	20
	Start drilling	3	50
305.75	Stuck rods	3	45
	Drop overshot	9	30
	Overshot seated	1	10
	Inner barrel at surface	1	20
	Total elapsed time	66	35

Diamond bits used with the L-series core barrel were replaced after about 250 feet of core drilling. The diamond loss per bit was about 9 carats, valued at $100.00.

The wire-line diamond bit showed little wear after completion of 642.2 feet of core drilling. No attempt was made to estimate the diamond loss.

7/ Wire-line rods are now being made with three-thread joints.

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TABLE 7. - Noncore drilling and drilling with NX-size L-series core barrel, Hauber property, Wyo., 1957

	Noncore[1/]	Core[2/]
Total.....feet	22,571	1,680.7
Maximum hole..... do.	347	58
Minimum hole..... do.	220	10
Average depth..... do.	309.2	25.1
Core recovery:		
Overall.....percent	-	95.7
Minimum..... do.	-	36.3

1/ 4-3/4-inch-diameter hole.
2/ 2-1/8-inch-diameter core.

TABLE 8. - Noncore drilling and drilling with NX-size wire-line equipment, Hauber property, Wyo., 1957

	Noncore[1/]	Core[2/]
Total.....feet	4,750	3/275.2
Maximum hole.....do.	330	32
Minimum hole.....do.	290	7
Average depth.....do.	304.7	18.3
Core recovery:		
Overall.....percent	-	3/96.0
Minimum.....do.	-	75.0

1/ 4-3/4-inch-diameter hole.
2/ 1-9/16-inch-diameter core.
3/ 1 hole cored from surface, 367 feet deep with 98-percent-core recovery, not included in calculations.

Practice at Jackpile Mine

E. J. Longyear, Inc. began exploratory drilling at Anaconda Co.'s Jackpile mine in 1953. In 1955, core drilling by conventional methods was discontinued, and the wire-line method was adopted.

Until late in 1957, the core drilling was confined principally to the Westwater member of the Jurassic Morrison formation; thereafter, many holes were core drilled 150 feet or more into the underlying Recapture Creek mudstone member of the Morrison formation.

Equipment used in noncore drilling through alluvium or Mesa Verde and Dakota formations consisted of truck-mounted, swivel-head, hydraulic-feed Longyear drill rigs, with NU-size drill rods and 4-1/4-inch tricone rock bits. Flush-coupled NX casing was placed in all holes before core drilling.

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Coring equipment in use in February 1958 consisted of the standard Longyear drill rigs, NXWL drill rods in 10-foot lengths and with 3-thread joints, and NXWL 10-foot core barrels.

Table 9 summarizes the data from 31 holes drilled during October 1957.

TABLE 9. - Summary of footage data for 31 holes, Jackpile mine, Grants district, N. Mex., 1957

Total noncored and cored.....feet	8,435
Average depth.....do.	272
Total noncored.....do.	2,585
Total cored.....do.	5,850
Average cored per hole.....do.	189
Deepest interval cored.....do.	190-815
Average core recovery.....percent	82

Core drilling in the interbedded shale-mudstones and sandstones required close supervision by the drill operator to attain maximum core recovery and penetration rates. The general operational data is presented in table 10.

TABLE 10. - Operational data, drilling with NX wire-line equipment Jackpile mine, Grants district, N. Mex., 1957-58

	Coring in sandstone and shale-mudstone
Pump pressure.....p.s.i.	100 to 600
Pump volume.....g.p.m.	15 to 35
Weight on bit.....lbs.	350 to 2000
Rotation rate.....r.p.m.	300 to 900

Holes were drilled noncore in the Cretaceous Dakota formation (Kd), to about 10 feet above the Dakota-Morrison contact. In areas where the Dakota formation was absent, coring was begun immediately below the alluvium. Coring was continued through the Jurassic Westwater (upper Morrison) sandstone (Jwc) and at least 150 feet into the underlying Recapture Creek mudstone (Jrc). Core runs were 5 feet long in sandstone and 10 feet long in mudstone. Table 11 presents the coring results obtained in the various formations.

TABLE 11. - Core drilling results; wire-line equipment, Jackpile mine, Grants district, N. Mex., 1957-58

Hole No.	Total depth, feet	Interval cored, feet	Core recovery, percent	
			Kd-Jwc	Jrc
1705.....	500	325-500	96	96
1709.....	815	200-495	93	92
1712.....	585	190-815	51	94
1715.....	495	230-565	96	81
1733.....	585	2-585	92	89
Average per hole.....	596	-	86	90

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Results obtained from conventional diamond-core drilling and those obtained using wire-line equipment can be compared from data presented in table 12. All drilling was done under similar surface and subsurface conditions.

TABLE 12. - Core-drilling results; conventional equipment and wire-line equipment, Jackpile mine, Grants district, N. Mex.

Period	Type core recovery	Feet cored	Average core recovery, percent
7/1/53 - 9/30/53.....	Conventional	7,408	69
2/1/55 - 4/30/55.....	do.	3,527	84
Average.....	do.	-	73.2
2/1/55 - 4/30/55.....	Wireline	4,395	85
10/1/55 - 12/31/55.....	do.	10,180	89
10/1/57 - 12/31/57.....	do.	13,183	82
Average.....	do.	-	84.7

Table 12 shows that in 1955 core recovery obtained with conventional equipment was 84 percent, an increase of 15 percent over the recovery obtained during the earlier stages of the drilling program. The improvement in recovery probably was due to more experience with subsurface conditions and use of better core-drilling techniques on the part of the drilling crews.

Core recovery obtained with wire-line equipment ranged from 82 to 89 percent and averaged 84.7 percent. The average core recovery was only slightly better than recovery obtained with conventional equipment in 1955. However, the use of the wire-line equipment made possible a substantial increase in feet cored per shift.

Practice at Carr Fork Operation

E. J. Longyear Co. core drilled more than 30,000 feet from surface and underground drill sites for the Anaconda Co. at the Carr Fork property, Bingham Canyon, Utah. The work was completed in January 1958. Contract drilling was done in metamorphosed sediments and monzonite porphyry to a maximum hole depth of 2,890 feet from surface sites and to 2,083 feet from underground sites.

Drills used on the surface consisted of diesel-powered, skid-mounted 24-inch-stroke hydraulic-feed N head Longyear drills with a maximum rated capacity of 4,000 feet of A rods. Auxiliary surface equipment consisted of gasoline-powered wire-line hoists and gasoline-powered transmission-type 535 RQ Bean pumps. Pump discharge could be closely controlled at between 5 and 35 g.p.m. with drill-fluid pressures ranging from 300 to 1,000 p.s.i.

Drills employed underground were air-powered hydraulic-feed 24-inch-stroke N head machines with a maximum rated capacity of 2,000 feet of A rods. Air-powered No. 435 Bean pumps and oil-hydraulic-powered wire-line hoists were auxiliary equipment (fig. 14). The air pressure was maintained at about 80 p.s.i.

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FIGURE 14. - Wire-Line Core Barrel Inner Tube Assembly at Hole Collar With AX Core From 1,604-Foot Depth. Wire-Line Hoist in Right Foreground.

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Conventional equipment used at the beginning of the program included various group designations of N, B, A, or E drill rods, as well as Longyear bits and 10-foot core barrels. Wire-line equipment in NX, BX, or AX size was adopted later in the program.

All holes drilled from the surface were vertical and were collared with NX-size bits, with the expectation that the hole size would be reduced by installation of casing. After introduction on the job, the wire-line equipment was used exclusively when the hole size was AX or greater. Conventional EX core bits, used when the hole size was reduced from AX, cut a core nearly the same size as AX wire-line core.

Underground drill stations were cut to provide space for 20-foot rod pulls. Wire-line equipment was used except in holes cased to less than AX size, or in holes inclined at less than 35° below horizontal. Seventy-five percent of the total drilling was accomplished with wire-line equipment.

As the purpose of the drilling was to obtain geologic information, good core recovery was essential. A core recovery of only 37 percent was obtained with the rigid-tube-type core barrels used early in the drilling program. Core recovery was increased to 81 percent by L-series or wire-line core barrels equipped with water-shutoff rubber washers. Most of the difficulty encountered in drilling resulted from penetration of loosely consolidated material. Loss of circulation and hole caving were controlled by using heavy drilling mud, stabilizing agents, cement, or as a last resort, by installing casing.

Diamond plug bits were used for drilling through cement and for by-passing stuck rods, bits, or foreign material in the hole. Plug-bit drilling totaled 65 feet from surface locations and 61 feet from underground locations.

Practice With NX Wire Line Equipment in 6-3/4-Inch-Diameter Holes

Early in 1958, contractor L. Materi successfully utilized E. J. Longyear NX-size wire-line equipment to recover core at depths of 1,200-2,500 feet while slim-hole drilling for gas and oil in east-central Wyoming. All drilling was done with a Winter-Weiss Portadrill 3000 chainfeed rig.

Exploratory holes 6-3/4 inches in diameter were drilled noncore to a predetermined depth. Externally upset J-55 oil-pump pipe with 2.441-inch I. D. couplings served as drill rods in the noncore interval of the hole. For subsequent core drilling, a 20-foot-long, NX, wire-line coring assembly with 40 feet of NXWL drill rods was attached to the J-55 oil-pump pipe.

Normal wire-line core-drilling procedure was followed, except that only one inner tube assembly was required. When the core was removed, the bit was raised about 20 feet off the hole bottom without previously conditioning the hole. The overshot was then dropped, and the inner tube assembly was extracted. The drill rods were then reconnected, and without the inner-tube-assembly in place, the drill fluid was circulated to condition the hole. Circulation was maintained while a geologist examined the core and decided

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if more core should be taken. If the hole was to be deepened after coring, the wire-line equipment was removed. A rock bit was used to ream the cored section and for subsequent noncore drilling.

Conventional 6-1/4- by 2-1/8-inch diamond bits were normally used by oil-well drillers in the district to recover core from the severely fractured Newcastle sandstone. An average rig time of 24 hours was required to cut and remove the core from 30 feet of hole drilled in this formation. When the conventional bits were used, recovery averaged 60 percent.

With the adapted wire-line equipment, 30 feet of core was cut and removed in 8 hours of rig time, and core recovery ranged from 96 to 100 percent.

The 1-9/16-inch-diameter core was somewhat smaller than that preferred by the oil companies, but the considerable saving in time and the greatly increased core recovery were favorable offsetting factors.

Recovering Core With the Freezing Method

A method of core drilling through loose overburden, unconsolidated rock formations, or placer deposits, with a diamond drill and a low-temperature fluid as the circulating medium, is described briefly in Diamond Drill Handbook (5, p. 189). The circulating fluid must be chilled to about minus 10° F. to freeze continuously water-bearing sediments into a cohesive mass ahead of the coring bit. A significant water content is essential to frozen-core drilling. The method was used by John D. Bardill[8/] when drilling on a Bureau of Mines project near Newton Falls, N. Y., in 1944.

The recovery of core by the freezing method, from unconsolidated sediments in central Wyoming, was described by H. F. Bartlett[9/] at a meeting of the Wyoming Mining Association, April 26, 1956, and in an article in Mining World, September 1956 (2). R. R. Carver[10/] described the method at the National Western Mining Conference in Denver, Colo., in February 1957 and at the Seventh Annual Drilling Symposium held October 3--5, 1957 (4, pp. 132-136). Another short article on the subject was published in August 1956 (6).

The core-freezing method now being used was developed through the mutual efforts of Utah Construction Co. and Lucky Mc Mining Co. personnel when drilling on the Lucky Mc property in the Gas Hills district of Wyoming during the winter of 1955-56. Sprague & Henwood, Inc., equipment was used in the drilling program. Little specific information was available concerning refrigerants, procedures, and costs, but it was decided that dewaxed diesel oil cooled with dry ice (solid carbon dioxide) could be used as the circulating medium. A skid-mounted, insulated, 400-gallon-capacity tank was constructed for use as a sump in which the diesel oil could be chilled during drilling operations. A removable metal platform was installed a few inches above the bottom of the tank to support chunks of dry ice. The space below the platform served as a settling zone for the drill cuttings. The tank was set in

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8/ Metallurgist (general) Bureau of Mines, Region I, Spokane, Wash.
9/ Geologist, Lucky Mc Uranium Co., Riverton, Wyo.
10/ Western manager, Sprague & Henwood, Inc., Grand Junction, Colo.

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a pit a few feet from the drill hole so that the oil could flow by gravity from the hole collar into the tank (fig. 15).

When the freezing method was first used in Wyoming, the noncore portion of the hole was drilled wet, with water as the circulating medium. The water had to be removed from the hole before circulating the chilled diesel oil. This was done by first casing the hole and then circulating unchilled diesel oil through drill rods that extended to the bottom of the hole, thus displacing the water. Circulation of the oil was continued until the oil discharged from the hole was clear.

Other tests were conducted by these companies during the winter of 1956-57, in the hope of developing a mud fluid that could be used in both the noncore and frozen-core drilling. No satisfactory multiuse fluid was developed, but the companies found that an inverted oil-emulsion fluid would coat the walls of the noncore portion of the hole with a cake that prevented caving and fluid loss to the formations and thus eliminated the need for casing. The inverted oil-emulsion medium is relatively expensive, and its use requires a four-man crew. Air or water mediums, on the other hand, are comparatively inexpensive and require only a three-man crew but involve installation of casing.

An ordinary oil-emulsion fluid was found satisfactory in some noncore drilling. However, fluid characteristics were adversely affected when excessive flows of ground water were encountered.

A fire hazard exists when diesel oil is used as a drilling fluid, and the danger is increased during cold weather when oil-burning space heaters are used near the drill rig.

The estimated cost of a hypothetical 250-foot frozen-core hole, with one 30-foot cored interval, is $780. This estimate assumes that normal drilling conditions exist and that the hole is favorably located near a source of dry ice. Of the $780 total cost of the hole, the noncore portion cost $330 and the cored portion cost $450.

Cost of noncore drilling is approximately one-tenth the cost of frozen-core drilling. When mineralized beds alternate with barren formations, two drilling procedures are possible. The entire interbedded interval can be core drilled, or core drilling can be limited to the mineralized beds, and the cheaper noncore method can be used in the barren zones. The alternation of coring and noncoring, however, is operationally inconvenient and approximately doubles the cost of chilling medium (4, p. 135). Choice of procedure largely depends on the relative thicknesses of the mineralized and barren beds.

The drill site is usually far from a source of dry ice, so delivery timing is of utmost importance. Suitable field-storage facilities for large quantities of dry ice have not been developed.

Contract-drilling rates for frozen-core drilling depend primarily upon total footage of proposed drilling and length of cored interval, as well as geographic location and ground conditions. The experience and knowledge of

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FIGURE 15. - Oil-Chilling Tank in Bulldozed Pit Beside Drill Site. Aljob Property, Gas Hills District, Wyo.

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the drill operator is of prime consideration when contemplating a project involving the freezing method.

BXM core barrels used in frozen-core experiments produced results similar to those obtained by means of NXM core barrels in which a core recovery of 98 percent or better is considered normal (fig. 16).

Experiments utilizing the E. J. Longyear wire-line equipment and the freezing method are now in progress, but results to January 1958 were not conclusive.

Practice at the Aljob Property

Sprague & Henwood, Inc. equipment was being used in January 1958 to drill exploratory holes for Union Carbide Nuclear Co. on the Aljob property in the eastern part of the Gas Hills district of Wyoming. The holes were drilled in the Tertiary Wind River formation.

Noncore holes were drilled to depths of 50 to 160 feet and then were completed by frozen-core methods. A Sprague & Henwood, Type 142, truck-mounted drill rig with twin-hydraulic, 24-inch-run cyl. was used for all drilling. Noncore drilling was done with 4-3/4-inch, roller-type rock bits on 4-thread N rods. The upper 10 to 30 feet of the holes were drilled through dry gravel containing pebbles up to 1 inch. The remainder of the noncore drilling was in moist, coarse, partly agglomerated sand, interbedded with shale and siltstone. Cuttings were flushed from the holes with compressed air from an Ingersoll-Rand Gyro-Flo compressor rated at 600 c.f.m. at 100 p.s.i. While drilling was in progress, the compressor worked continuously in compressing air to an outlet pressure of about 96 p.s.i.

The drillers were usually able to keep a hole open long enough to complete the noncore drilling and insert the NX flush-coupled casing. To control caving, noncore drilling was stopped at about 10-foot intervals, and 50 to 60 gallons of water was pumped into the hole. The water was then flushed out of the hole with compressed air. The water and cuttings scoured the hole walls and removed any mud collars that might have formed during drilling. The water also removed coarse cuttings or gravel that had sloughed into the hole and were too heavy to be removed by air flushing. During subsequent dry drilling, an accumulation of fine cuttings helped reinforce the damp walls of the hole. More frequent flushing with water was required if the hole tended to cave. When cuttings were expelled from the hole, samples were taken at 2-foot intervalls. Because of the need to maintain a straight hole and of the frequent interruptions for water flushing, the maximum amount of noncore drilling that could be accomplished in one 8-hour shift was about 150 feet.

The cored section ranged from 28 to 56 feet in length. The material penetrated consisted of unconsolidated sand containing coarse gravel and scattered cobblestones up to 4 inches in diameter. Conventional NXM 10- or 20-foot core barrels were used with Tuffset bits having 4 waterways and set with 30-per-carat diamonds. The crown-block was 28 feet above the ground, and two 10-foot sections of rod could be handled in one pull.

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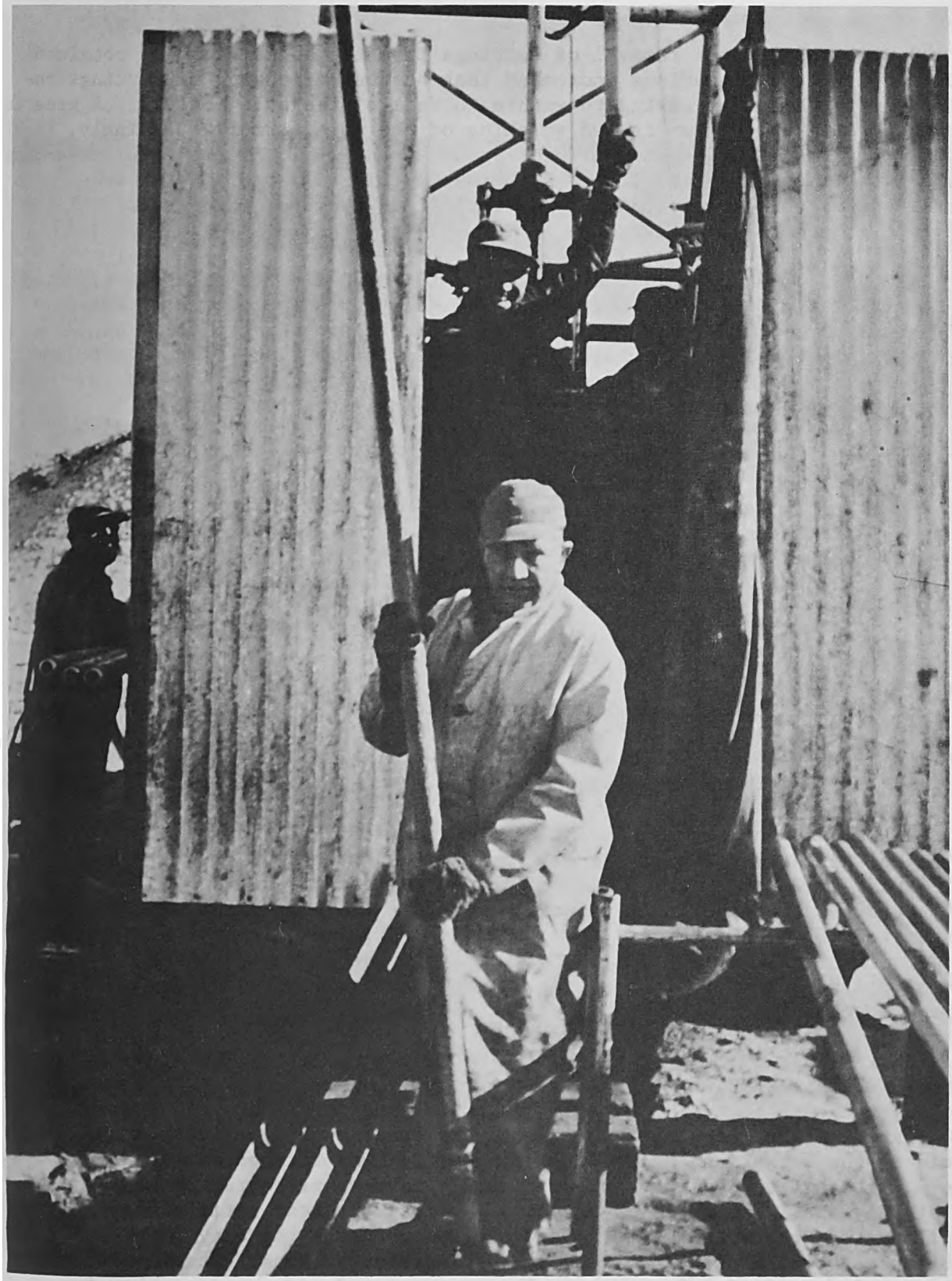

FIGURE 16. - Frozen Core Removed From Core Barrel. *(Courtesy of Utah Mining Corp.)*

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Casing facilitates removal of cuttings from the hole. Results obtained from the drilling operations indicated that adequate flushing of cuttings required installation of casing to within 20 feet of the hole bottom. A greater length of open hole often caused sticking of the core barrel. Seemingly, in the comparatively large-diameter section of uncased hole, velocity of ascending medium was insufficient to lift the coarser cuttings. Freeing of a stuck core barrel was usually accomplished by overdrilling with a casing shoe to enlarge the hole around the core barrel.

As thawing in the hole takes place in 20 to 30 minutes after circulation of the chilled fluid is stopped, excessive delay in extracting the core barrel usually results in considerable loss of the disintegrated core (fig. 17). However, in one hole at the Aljob project, only slight loss of core resulted from a 24-hour delay in removing the core barrel, presumably because the thawed core was sufficiently cohesive to remain in the core barrel.

When the core barrel had been removed and the casing had been extended, a dull, 2-1/2-inch carbide-insert drag bit was attached to the drill rods, and the assembly was lowered into the hole. Most of the water and mud were blown out with compressed air, and any material that had settled to the bottom was loosened with the drag bit. After the bottom of the hole was reached, blowing with compressed air was continued for 10 or 15 minutes to remove the remaining water.

While the hole was being dried, about 300 gallons of No. 1 diesel oil was being chilled in an uninsulated, open-topped steel water tank (fig. 18). One pound of dry ice will lower the temperature of 1 gallon of diesel oil about 50° F. in 20 to 30 minutes. The outside temperature was 20° F., so the diesel oil was cooled to minus 30° F. by the time the hole was dried and a diamond bit and core barrel were in drilling position.

A Bean 435 pump equipped with a four-speed transmission was then used to circulate the chilled diesel oil for about 10 minutes to freeze the unconsolidated sediments at the bottom of the hole ahead of the diamond bit. The drill rods were rotated slowly during the 10-minute period. All water must be removed from the pumping system, because any ice particles in the chilled diesel oil are likely to foul the pump or plug the passageways in the core barrel. A strainer, made from metal window screen, was placed over the pump intake hose to exclude wax and ice particles.

During the drilling operation, 10 to 12 g.p.m. of chilled oil was circulated. The oil was pumped from the tank at minus 30° F. and returned from the hole at plus 5° to 10° F. Pump-gage pressure was maintained at 200 to 250 p.s.i. Higher pressures were likely to cause excessive loss of drilling fluid to the formations being drilled. The bit was rotated at 100 to 150 r.p.m. with extremely light or occasionally reverse pressure. A bit with relatively small diamonds (30-per-carat) proved the most satisfactory for drilling the frozen sediments. Larger diamonds had a tendency to pull the pebbles and cobbles loose instead of cutting through them. The maximum coring rate was 2 feet in 2-1/2 minutes. The rate was reduced considerably when gravel and cobbles were encountered.

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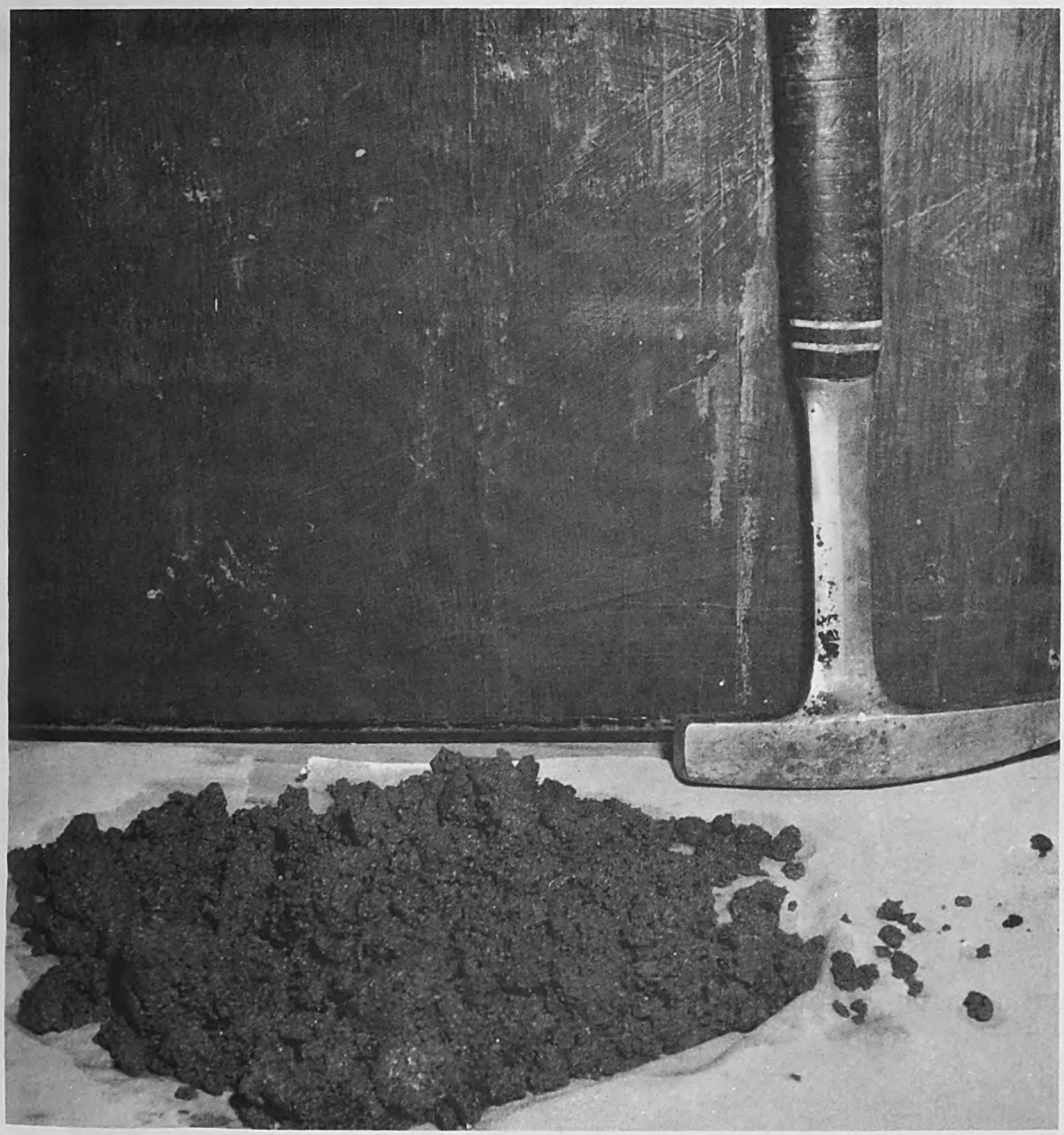

FIGURE 17. - Thawed Specimen of a Core Recovered by the Freezing Method.

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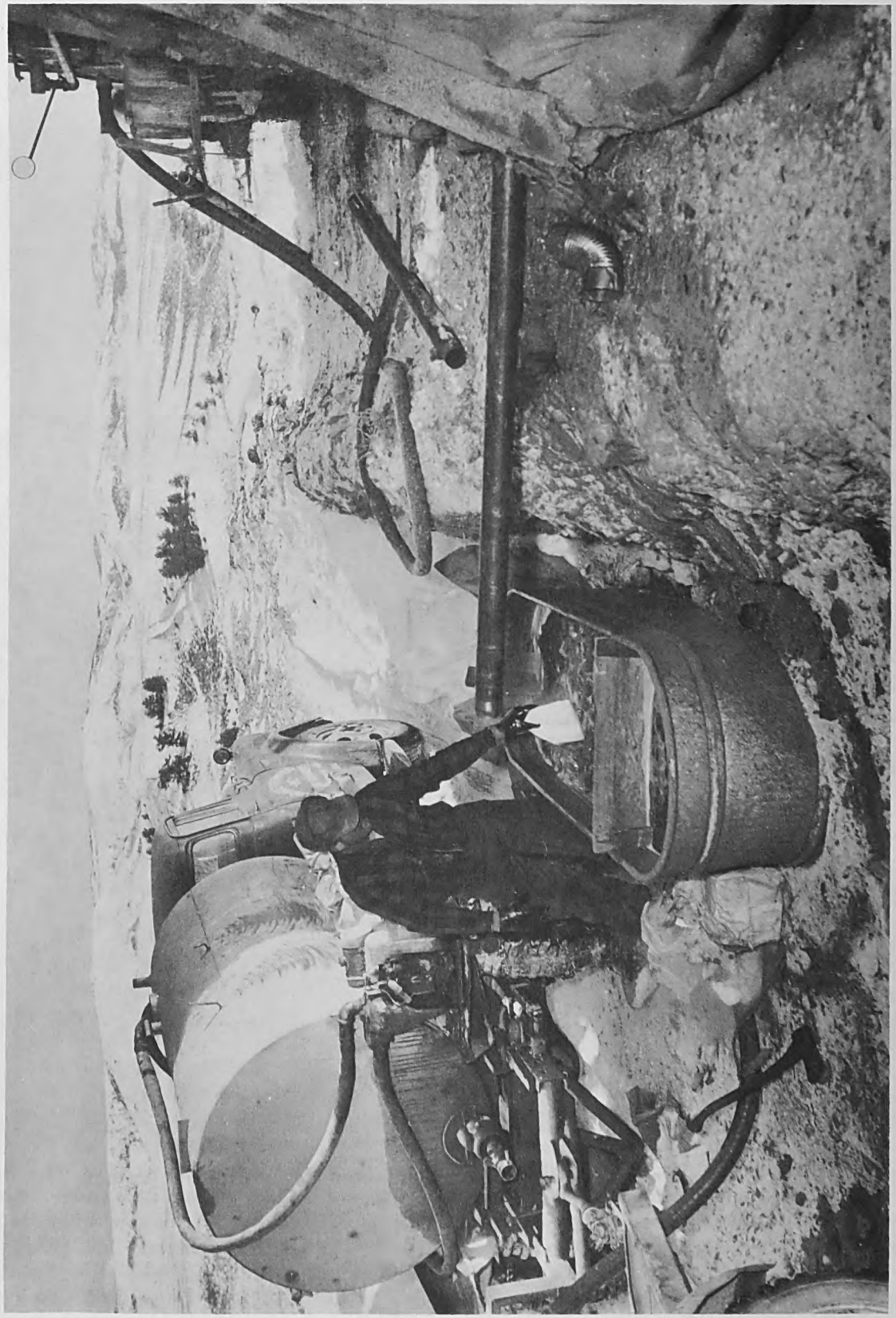

FIGURE 18. - Using Chunks of Dry Ice to Chill Diesel Oil for Frozen-Core Drilling. Note Liquid Turbulence Caused by Evaporation of Dry Ice.

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The hole was bottomed at 145 feet, and a 99-percent core recovery was obtained from the 28-foot interval that was core-drilled. The 1-percent-core loss occurred when the core barrel was being removed from the hole after having been stuck for 24 hours. When coring was completed, the diesel oil was recovered from the hole by blowing it out with compressed air. Casing was recovered if possible.

A cost analysis of frozen-core drilling at the Aljob property is not available. However, Vitro Uranium Co. completed one frozen-core hole in the Gas Hills district, with a rented drill rig, and the following direct costs were incurred:

TABLE 13. - Direct costs of frozen-core drilling, Vitro Uranium Co., Jan. 1956

Noncore drilling, 110 feet at $0.70 per foot	$77.00
Diesel oil, 860 gallons at $0.17 per gal	146.20
Dry ice, 2,400 pounds at $0.07 per lb	168.16
Core drilling, 33 feet at $6.00 per foot, ($5.10 per foot for 85 percent recovery)	168.30
Casing, 110 feet at $1.00 per foot	110.00
Supervising engineer, 9-1/2 hours	25.00
Standby time, 1 hour	12.00
Location work	29.59
Total	$706.25

The cost for casing should be included with the cost for core-drilling. Thus, the direct cost of core drilling the 33-foot interval was $19.07 per foot. These figures are based on drilling experience in one hole and are presented for comparison only.

Recovering Core from Loosely Consolidated Formations with a Pilot-Type Bit

Core-drilling in loosely consolidated formations, and with only a small quantity of circulating water to minimize core erosion, has been common practice for many years. The Christensen Diamond Products Co., Salt Lake City, Utah, manufactures a pilot-type bit and a swivel-type core barrel that were used successfully in recovering core from loosely consolidated sediments of the Tertiary Wind River formation in the Gas Hills district of central Wyoming (7). The core-lifter assembly on the inner tube of a 4-1/2- by 3-inch double-tube, swivel-type core barrel was replaced with a straight-wall, inner-tube shoe (fig. 19). The inner tube was adjusted in the core barrel so that the inner-tube shoe was almost in contact with the rear portion of the bit face, thereby keeping most of the circulating medium from entering the throat of the coring bit. The circulating medium was discharged through face ports on the reaming portion of the bit that is almost 1 inch behind the coring pilot face (fig. 20), thus reducing to a minimum the washing of core by the circulating medium. At the end of a core run, the drill operator dryblocks the core in the throat of the bit by shutting off the pump, increasing the weight on the bit, and maintaining bit rotation for a short time.

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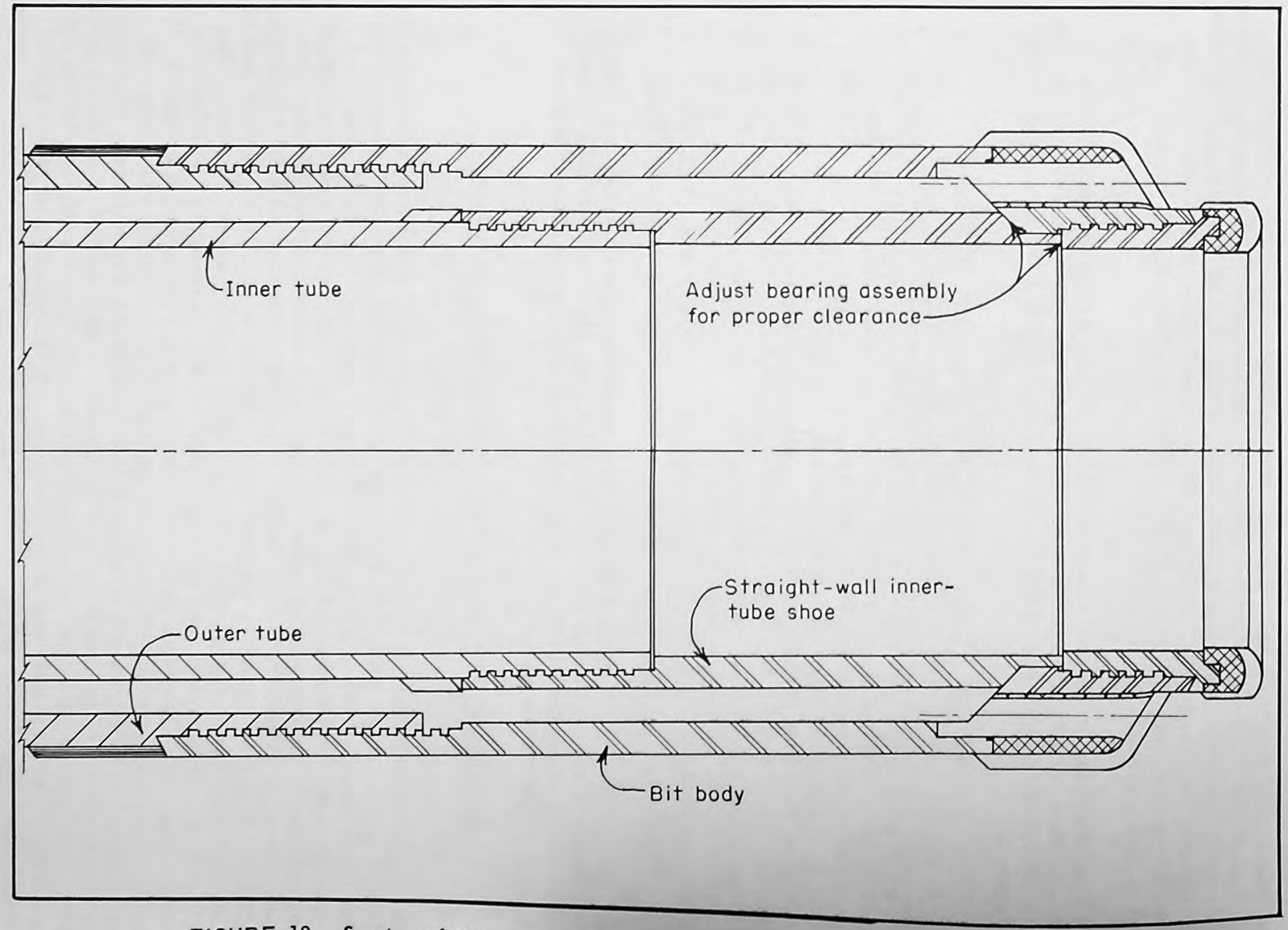

FIGURE 19. - Section of Pilot-Type Bit and Bottom End of 4½- by 3-Inch Core Barrel.
(Courtesy of Christensen Diamond Products Co.)

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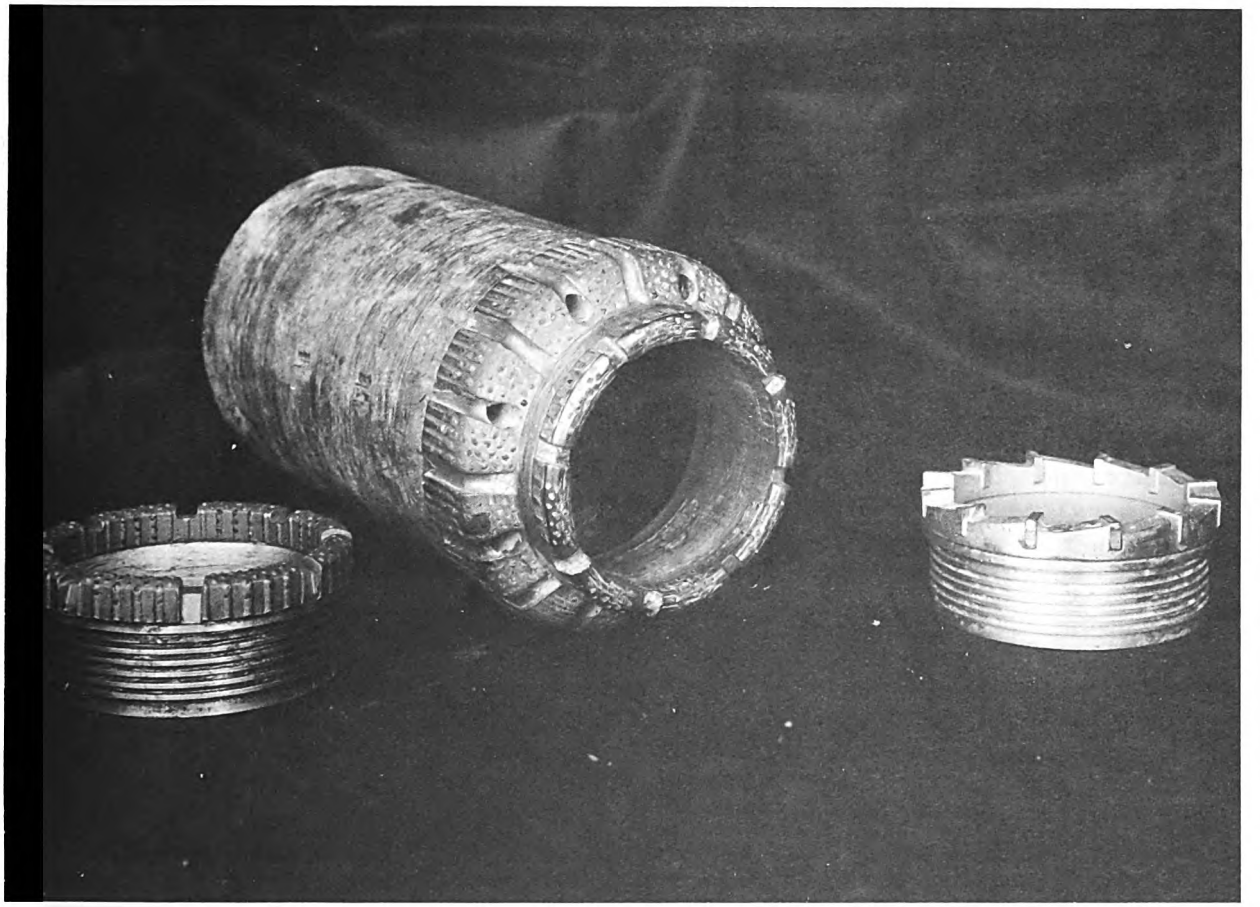

FIGURE 20. - Pilot-Type Bit for Cutting 3-Inch Core. Note Face Discharge Ports and Replacement Pilot Bits, Diamond or Tungsten Carbide Insert.

A water-base mud mixture, having a 40- to 45-seconds-per-quart viscosity, is circulated at a low volume when drilling with the pilot-type bit. The pilot bit cuts a core ahead of the circulating medium, so a low rotation rate is maintained to prevent premature blocking of the core. The pilot section of the bit wears faster than the reaming section, so the bit was designed with a detachable pilot section (fig. 19). The cutting edge of the pilot section consists of diamonds cast in a suitable matrix, or of tungsten-carbide inserts arranged in a saw-toothed design. The latter is satisfactory for core-drilling softer sediments.

Practice at the Day-Loma Claims

Contractor A. R. Ormsbee drilled for uranium on the Day-Loma claims in the southwestern portion of the Gas Hills district in central Wyoming during the fall and winter of 1957-58. The claims were controlled by Western Nuclear Corp., formerly Lost Creek Oil & Uranium Co.

The contractor's equipment consisted of rotary-table, chain-feed Failing CFD-1 and Mayhew 1000 drill rigs; water-tank trucks and truck-mounted compressors.

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Holes were drilled in the upper Tertiary Wind River formation. This formation comprises the following members:

TABLE 14. - General stratigraphic section on Day-Loma claims, Wyo.

Strata	Interval, feet	Thickness, feet
Talus or overburden.....	0 to 30	30
Unconsolidated sand.....	30 to 100	70
Sand and gravel.....	100 to 120	20
Loosely consolidated sandstone...	120 to 160	40
Loosely consolidated conglomerate containing numerous boulders...	160 to 190	30
Loosely consolidated sandstone with interbedded mudstone.....	190 to 280	90
Interbedded sandstone, conglomerate, and mudstone.....	280 to 420	140

Hole depths ranged from 120 to 450 feet and averaged 330 feet. Exploratory holes were drilled noncore on a 400-foot primary grid pattern and were probed with radiometric equipment. Mineralized zones indicated by probing an exploratory hole were verified by core drilling in an offset hole at a distance of 10 to 15 feet from the original hole. The offset hole was drilled noncore through the barren sections and was core drilled through the mineralized zones.

A primary reason for core drilling was to obtain reliable samples for chemical analyses. The assays were carefully correlated with radiometric probe results, and a chemical-to-radiometric ratio was established for unoxidized ores. The uranium (U_3O_8) content as determined by chemical analyses was consistently the higher. For lower grade ores the ratio was about 2 (0.19 percent U_3O_8 to 0.10 percent equivalent U_3O_8). In higher grade ores the ratio was closer to 1 (0.88 percent U_3O_8 to 0.70 percent equivalent U_3O_8). Radiometric readings in the oxidized zone were so variable that no usable ratio could be established. After a firm ratio was established, noncore holes were drilled and probed. The radiometric probing results were adjusted according to the ratio and served as a basis for ore-reserve estimates. Core-drilling was relatively expensive, so only 1 hole in 75 was core-drilled.

Holes were drilled noncore with 5-5/8- or 6-1/4-inch roller- or drag-type rock bits attached to 2-3/8-inch exploration drill pipe. The larger bits could better withstand the severe shocks sustained when drilling through clusters of boulders and pebbles. A low-viscosity, water-base mud mixture was circulated to remove drill cuttings and to retard caving by coating the hole wall with a mud cake.

In drilling with a pilot-type bit on a 4-1/2- by 3-inch core barrel, about 20 g.p.m. of freshly-mixed drill fluid was circulated at a pump-gage pressure of 100 to 200 p.s.i. The pump used was a 4- by 6-inch duplex with 3-inch cylinder liners. The discharge of the pump could be controlled closely by manipulating the four-speed transmission and adjusting the pump motor.

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The bit was rotated 40 to 45 r.p.m., and the weight on the bit was about 3,800 pounds. Oil was delivered to the hydraulic motor of the chain-feed mechanism under a pressure of 150-160 p.s.i. A 5-foot-long core barrel was used, and coring runs ranged from 1 to 5 feet. The average run was 4 feet. The average rate of advance in core-drilling in all members of the Wind River formation was 5 feet an hour. When drilling loosely consolidated sandstone, the average coring rate was 8 feet an hour.

Bentonite or a similar clay, contained in most members of the Wind River formation, swells when it absorbs water, so the core usually was packed tightly in the inner tube. To remove the core, one end of a 1-inch hose was attached to the back end of the 3-inch inner tube, and the other end was connected to the drill-rig pump. The core was then forced out of the inner tube by carefully applying drill fluid under pressure controlled through a gate valve (fig. 21). Besides packing in the core barrel by swelling, the core from some formations was elongated, thus making the measured core length greater than the core-drilled interval. Based on such measurements, core recovery averaged 99.0 percent in 426 feet of core-drilling in 13 holes.

FIGURE 21. - Core Extruded From Inner Tube by Drill-Fluid Pressure.

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Minimum measured core recovery for any one hole was 73.8 percent, and maximum recovery was 113.3 percent. Correction for elongation, caused by expansion, must be made when logging the core. The contractor was not paid for any footage drilled in a cored hole when core recovery was less than 80 percent. When recovery was between 80 and 90 percent, he was paid in accordance with the percent recovery, and when core recovery exceeded 90 percent, he received the full contract rate.

PNEUMATIC-PERCUSSIVE DRILLING

Truck-Mounted Pneumatic-Percussive Drills

Practice at Dulaney Mining Co.

The Dulaney Mining Co. property, southwest of Slick Rock, San Miguel County, Colo., includes the Radium claim group and the Ike claim group. Uranium minerals in these claim groups occur in the Salt Wash member of the Jurassic Morrison formation.

All exploration and development drilling was done with two truck-mounted pneumatic-percussive drills operated by company employees. In 1957, the drill-hole depths ranged from 100 to 200 feet and averaged 140 feet. One of the drills was mounted on a two-wheel-drive vehicle; the other was one a six-wheel-drive vehicle. The drill operators preferred the six-wheel-drive drill rig for most drilling, although the two-wheel-drive rig was less cumbersome. On each drill rig, a Chicago Pneumatic, 365 Power Vane rotary compressor furnished compressed air at 96 p.s.i. outlet pressure to a Gardner Denver D99 rock drill. The drill was bolted to a slideplate held by guides to a 20-foot mast that was hinged at the front end of the vehicle. The mast could be laid back over the truck cab when the drill rig was moved. The drill rigs used 15-foot sections of 1-1/4-inch-diameter long-hole drill rods. On each drill-rod connector, four weld beads about 1/4-inch high and 1-1/4-inches long are run parallel to and are spaced equidistantly around the long axis of the connector (fig. 22). They help loosen material that might build up on the hole wall; also, the beads serve as lugs that can be gripped with a wrench when loosening the threaded drill-rod connections. The 20-foot mast provided an extra 5 feet of headroom that was useful when freeing stuck drill rods.

Cross-type 2-1/2-inch-diameter bits with tungsten-carbide inserts that extended about one-fourth inch outside the bit body were the most satisfactory bits for drilling in loose overburden, clay, mudstone, and broken ground. A new bit could be used to drill 300 to 400 feet of hole before it needed sharpening, but thereafter the bit had to be resharpened after each 150 feet of hole.

In December 1957, six holes totaling 915 feet were drilled in one 10-hour shift. Four hundred feet of drilling per 8-hour shift was considered the normal amount if no breakdowns occurred. Depth of drilling, if less than 200 feet, did not affect materially the drilling rate per shift. The drillers would not start a hole unless it could be completed by the end of the shift as water would seep into the hole and would make subsequent drilling difficult. The water and cuttings would form mud on the holewall, making cuttings samples

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and radiometric probing results unreliable. As drilling progressed, the cuttings and dust were caught in an open can and were used as samples (fig. 22). The sample interval was 2 feet in waste and 1 foot in mineralized zones. After completion, the hole was probed with radiometric equipment, and the results were logged.

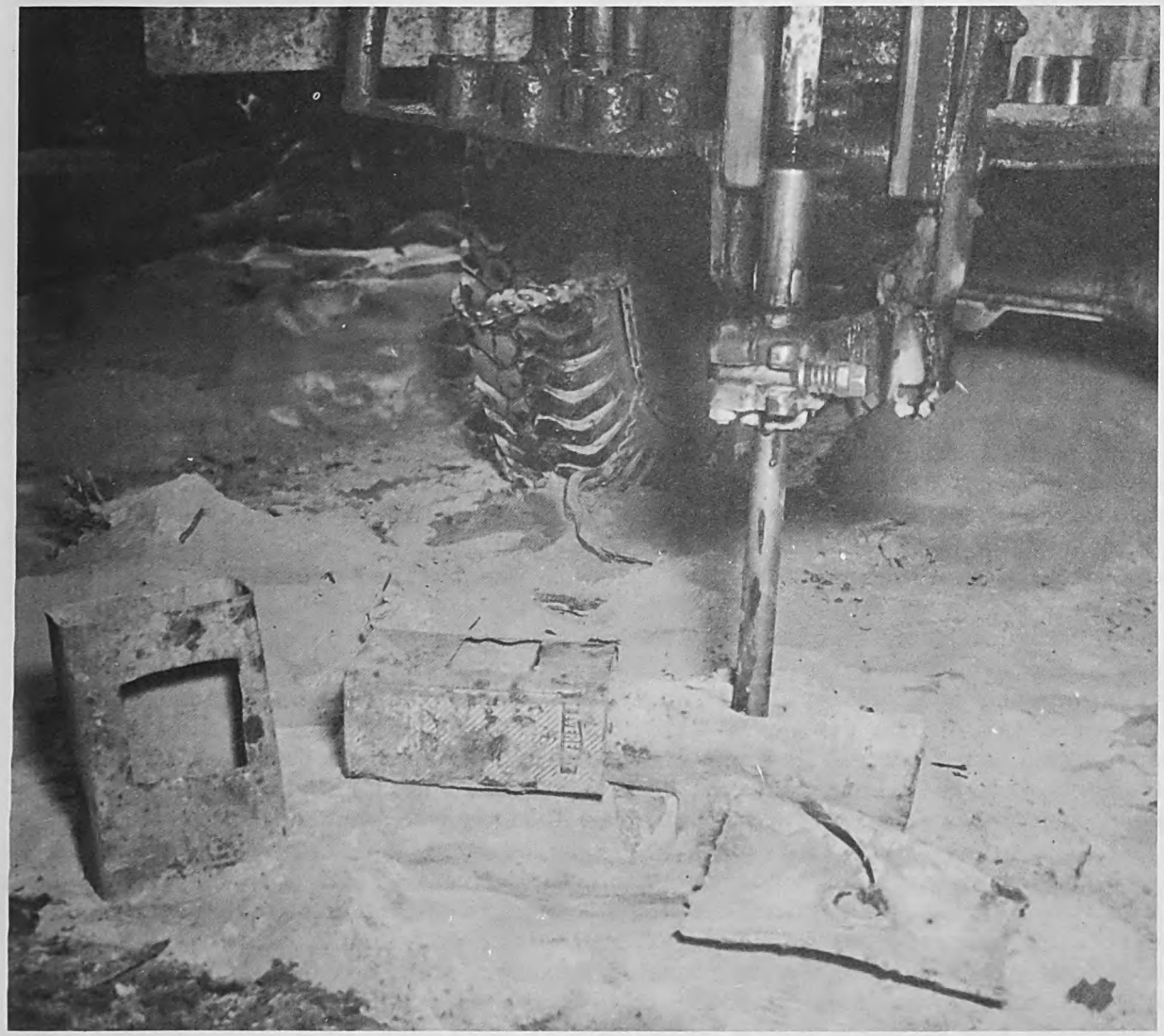

FIGURE 22. - Cans Used to Catch Samples of Drill Cuttings and Dust. Dust Seal in Right Foreground Rests on Top of Deflector Tee During Drilling. Note Weld Beads on Rod Connector Above Rod-Guide Unit.

The arithmetic average of the uranium content, as indicated by chemical analyses of cuttings and radiometric probing of holes, was used in estimating ore reserves, because the chemical analyses tended to be low and probing results were usually high. Tonnage estimates based on the results of drilling were within 25 percent, plus or minus, of the amount of ore actually produced from the ore bodies.

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Practice at the Bean Claims

Lippoth & Wein Drilling Co., late in 1956, completed 3,000 feet of pneumatic-percussive drilling on the Bean claims, Slick Rock district, San Miguel County, Colo. Drilling was done through interbedded sandstone and mudstone of the Jurassic Morrison formation.

The drill rig consisted of an International 6 by 6 army-surplus vehicle on which was mounted a Chicago Pneumatic Rotary compressor rated at 600 c.f.m. at 100 p.s.i. A Gardner-Denver D99D long-hole drifter with air back head was bolted to a slideplate on the 24-foot-long, channel-iron mast hinged to a heavy steel frame on the front bumper of the vehicle. Extended carbide-insert cross bits, 2-1/4 to 2-1/2 inches in diameter, with four side holes, were thread-connected to 18-foot sections of 1-1/4-inch round drill rods.

Hole depths ranged from 20 to 132 feet; the average depth was 90 feet. On-the-hole drilling rate ranged from 50 to 90 feet per hour. Dust and cuttings were collected for samples in a Ducon dust collector mounted on a steel framework on the front end of the drill rig (fig. 5). The cuttings were blown from the hole collar to the dust collector by a venturi device similar to the one shown in figure 23. The system caught about 95 percent of the drill cuttings that were lifted to the hole collar by compressed air discharged at the bit. Dust and cuttings were collected from 3-foot sections of hole in barren ground and from 1-foot sections in mineralized ground. The hole was blown clean after drilling each 1-foot section in mineralized ground.

In damp mudstone, the major problem was to remove the sticky drill cuttings and prevent plugging of the airholes in the bit. If moisture were not excessive, the cuttings could be dried by maintaining maximum discharge of compressed air at the bit while alternately advancing and retracting the bit about 1 inch at a time. Between bit advances, sufficient time was allowed for the compressed air to dry the hole bottom and drill cuttings. If excessive moisture were present, the hole was abandoned.

Loose granular sand tends to cave behind the bit. To prevent losing the bit and drill rods, the volume of air to operate the machine was reduced, and the penetration rate was reduced. The blow air was then usually adequate to remove the drill cuttings as well as the excess caved material. If the bit and drill rods were stuck in the hole, recovery was sometimes made possible by removing the rotation pawls from the rock drill and then running the machine while attempting to hoist the rods from the hole. A hydraulic jack or prybar might be used to increase the hoisting power.

Holes that collected water, or caved while standing, could be cleared for radiometric probing by removing the bit from the drill rods and inserting the rods into the hole with the blow-air valve wide open. When the hole bottom was reached, the air was turned off, and the drill rods were withdrawn.

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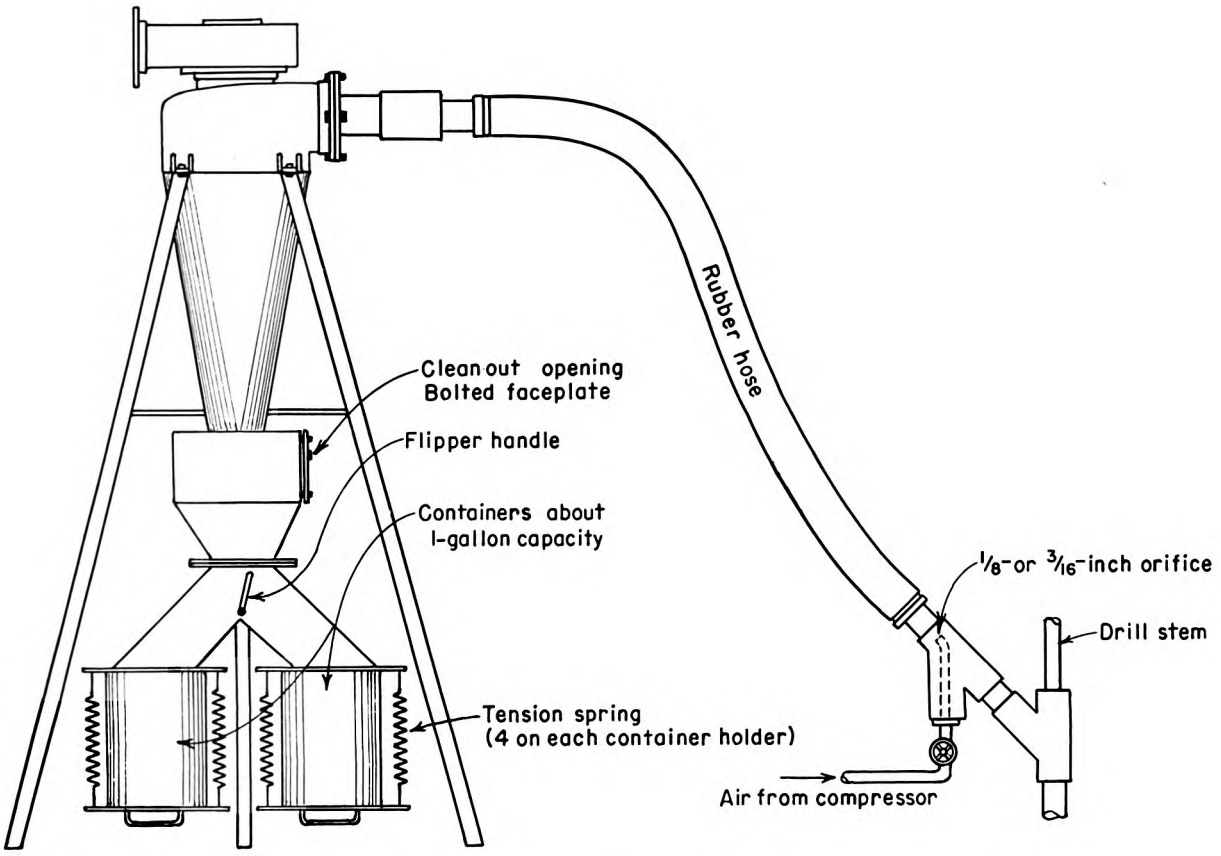

FIGURE 23. - Typical Cone-Type Dust Collector Arrangement.

Down-The-Hole Pneumatic-Percussive Drills

"Down-the-hole" or "bottom-hole" drills, as the description implies, are designed for insertion into bore holes. The objective is to provide percussion directly to the bit, thus preventing loss of efficiency resulting from transmission of impact through drill rods.

To persons concerned with 3- to 6-inch-diameter holes, commonly used in exploratory drilling, these recently developed down-the-hole machines should be of interest. The machines are not of the rotary-percussive type inasmuch as little of the cutting action results from rotary motion. The down-the-hole machine, with an X-type carbide insert bit attached, is adapted to the drill rods by a threaded connector (fig. 24). Compressed air supplied through the drill rods actuates the machine piston which strikes the bit anvil. Exhaust air flushes the cuttings from the hole (fig. 25).

The drill rods are rotated from the surface by a kelly bar and turntable, or a rotary drill chuck, or an independent motor. The cutting action of the bit is almost entirely due to percussion; rotation of the drill rods turns the machine and the bit. Thrust on the bit is supplied from the surface through the drill rods by pulldown or hydraulic mechanisms.

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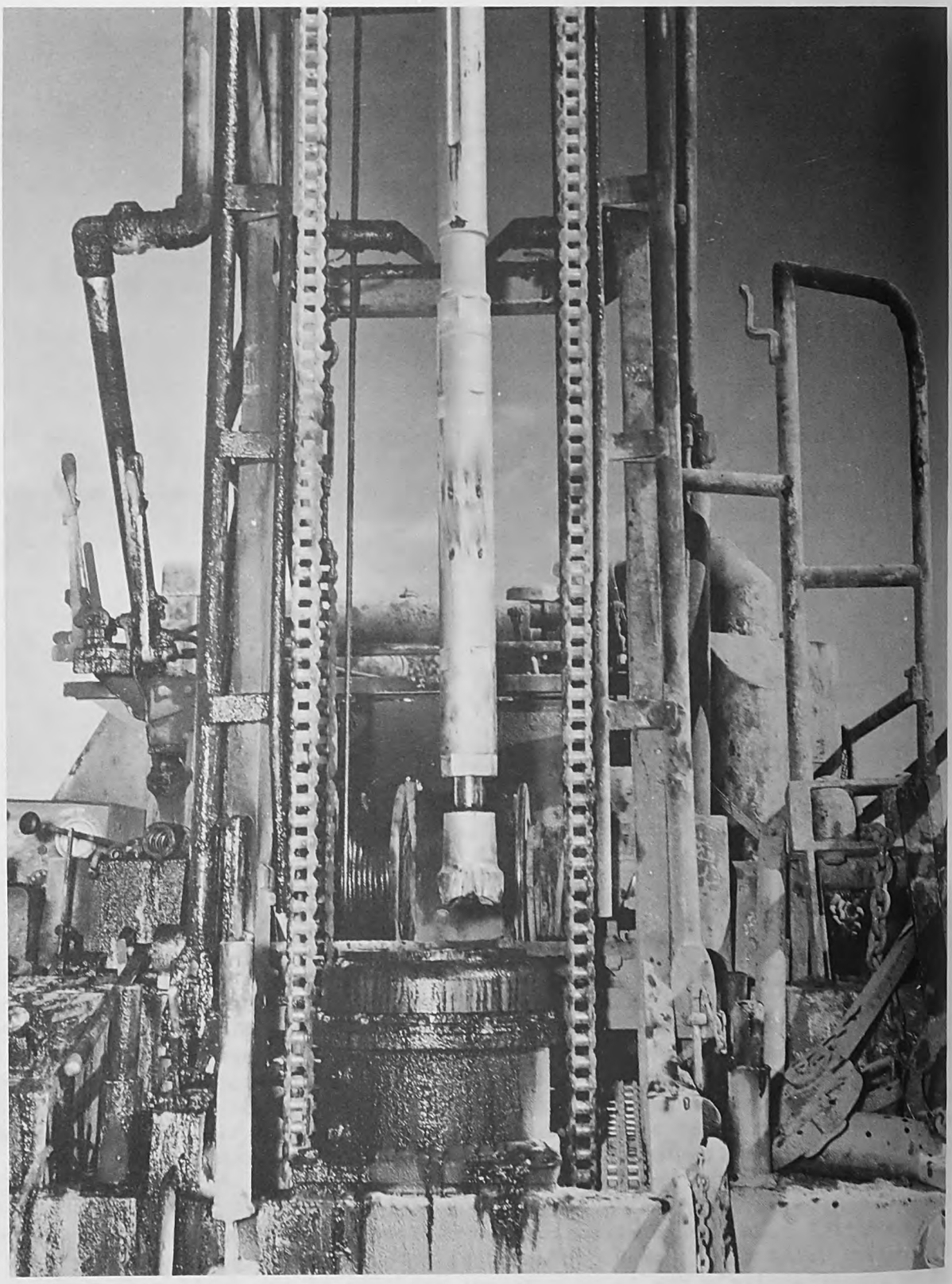

FIGURE 24. - A Down-the-Hole Machine, With 4¾-Inch, X-Type, Carbide Insert Bit, Connected to Kelly on a Chainfeed Drill Rig.

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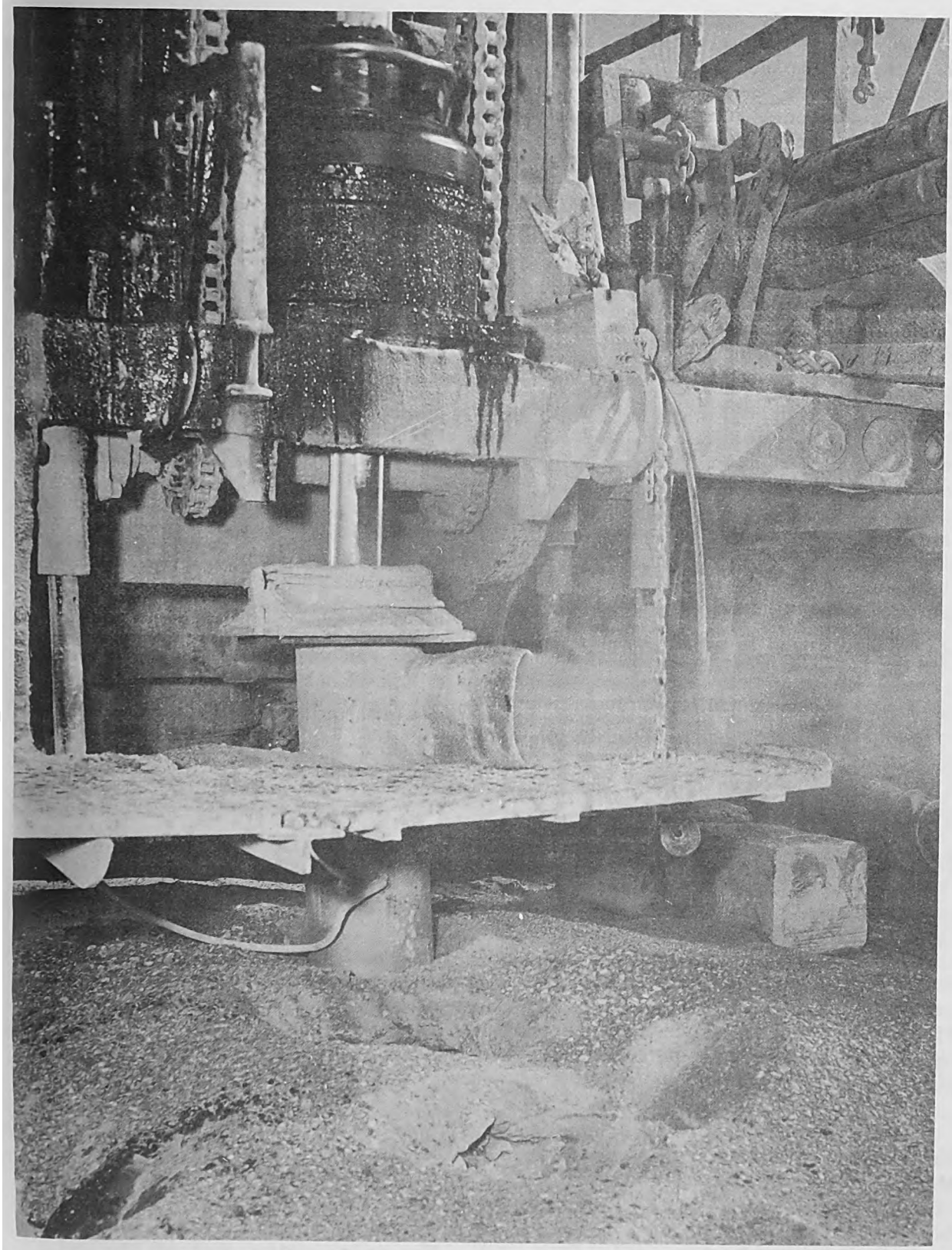

FIGURE 25. - Air Flushing Dust and Rock Particles From a 4¾-Inch Hole Drilled With a Down-the-Hole Machine.

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A down-the-hole machine was being tested in February 1958 by drilling 22-foot-deep holes, 4-3/4 inches in diameter, in Tertiary basalt caprock. The machine was used on a chain-feed drill rig that had a 3-7/8-inch kelly bar 22 feet long. The machine was being rotated at about 50 r.p.m. and was making 800 strokes per minute. Air compressed to 95 to 97 p.s.i. was supplied by a compressor rated at 300 c.f.m. The drilling rate averaged 0.9 foot per minute. The machine can be used in place of a roller-type rock bit for drilling in hard formations. Changing one for the other is relatively simple.

Contractor Bert Vivian used a Gardner-Denver M-4 Mole-Dril to drill through almost 100 feet of quartzite caprock in several holes on the north end of Big Indian district near Moab, Utah, in the early summer of 1958.

The Mole-Dril was mounted on 2-3/8-inch drill pipe attached to the heavy-duty kelly of a Mayhew 1000 drill rig. A Gardner-Denver piston-type compressor rated at 600 c.f.m. supplied compressed air at 80 to 90 p.s.i. pressure. The machine was rotated at about 20 r.p.m. with about 1,500 pounds weight on the bit for the length of the kelly, then slight chain-feed pressure for the remainder of the hole. Breakage and loss of tungsten carbide inserts in the bit were excessive, especially with greater weight on the bit. The bit-failure problem was partly solved by filling the slot in the bit with a relatively soft welding metal and then facing the metal with an electrode rod of a type used on cable-tool bits and having a Rockwell hardness of 60 to 62. The remodeled bit was quite satisfactory, but the drilling program was completed before comparative performance studies could be made. The drill contractor was enthusiastic about the machine and was sure that his bit costs were considerably less than would have been possible if roller-type rock bits had been used for the drilling. The roller-type rock bits were replaced after only 3 or 4 feet of drilling, even though the teeth were hard-surfaced.

SAMPLING UNCONSOLIDATED FORMATIONS WITH A DRY HOLE DIGGER

A bucket-type drill (fig. 26), locally known as a dry-hole digger, is extensively used in specialized drilling associated with petroleum production. It may also be known as a "rat-hole rig", "bucket drill", or "cesspool digger". The machine can be used for drilling a hole of any diameter between 12 and 96 inches in unconsolidated formations that can be auger-drilled. Numerous boulders, larger than the opening at the bottom of the drill bucket, might preclude drilling with the dry-hole digger. A digging bucket up to 32 inches in diameter will pass through the rotary table opening. If a larger than 32-inch-diameter hole is required, a pilot hole is dug first, and a reaming tool is used to enlarge the hole. The cuttings fall into the pilot hole and are removed with the bucket used to dig the pilot hole.

A scraper-type bit is hinged to the bottom of a digging bucket (fig. 27). The bucket is rotated at about 10 r.p.m. and is filled with loose material in about 6 revolutions while advancing 1 foot. The bucket is then withdrawn from the hole and dumped. The bucket is rotated by a square, telescoping drill stem that slides through a square opening in a steel frame that fits against lugs on the turntable (fig. 27). The telescoping part of the drill stem consists of two sections, each 20 feet long. The digging bucket is

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attached to the lower end of the inner section, and the hoist cable is attached to its upper end. The first 40 feet of drilling does not require the use of an additional drill stem. Additional drill-stem sections are available in 20-foot lengths.

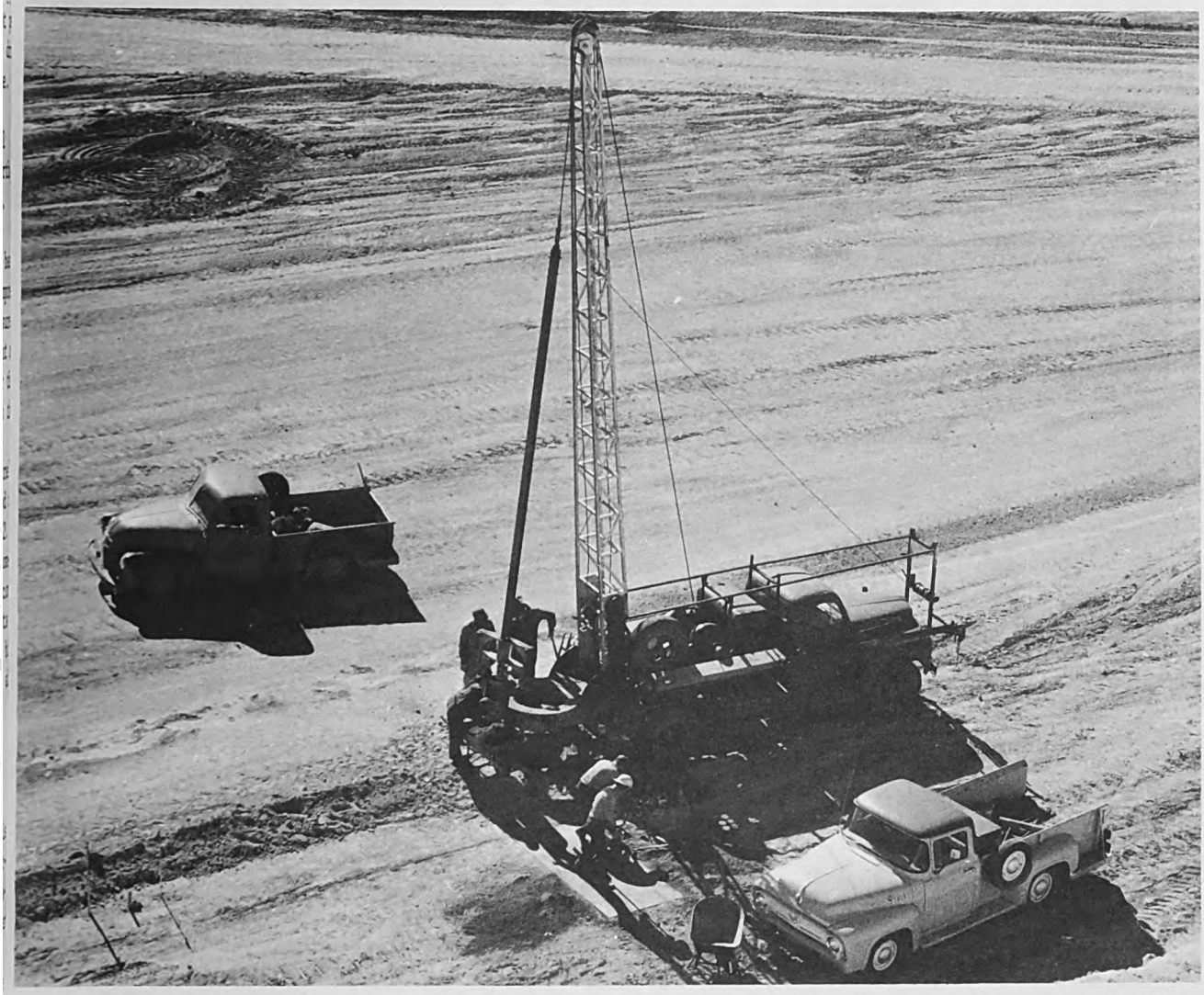

FIGURE 26. - Dry-Hole Digger Used to Drill 15-Inch-Diameter Holes for Mine Control Sampling at the Lucky Mc Mine.

A dry-hole digger, owned and operated by V. McDaniels, Riverton, Wyo., was used to recover large samples from unconsolidated strata in the upper Tertiary Wind River formation at the Lucky Mc mine in the Gas Hills district of central Wyoming.

Holes of 26-inch diameter were drilled to a depth of 135 feet on the Lucky Mc property in 1956. The accuracy of sampling with the digger was checked by taking channel samples from the walls of the holes. Results from the two methods of sampling were nearly identical.

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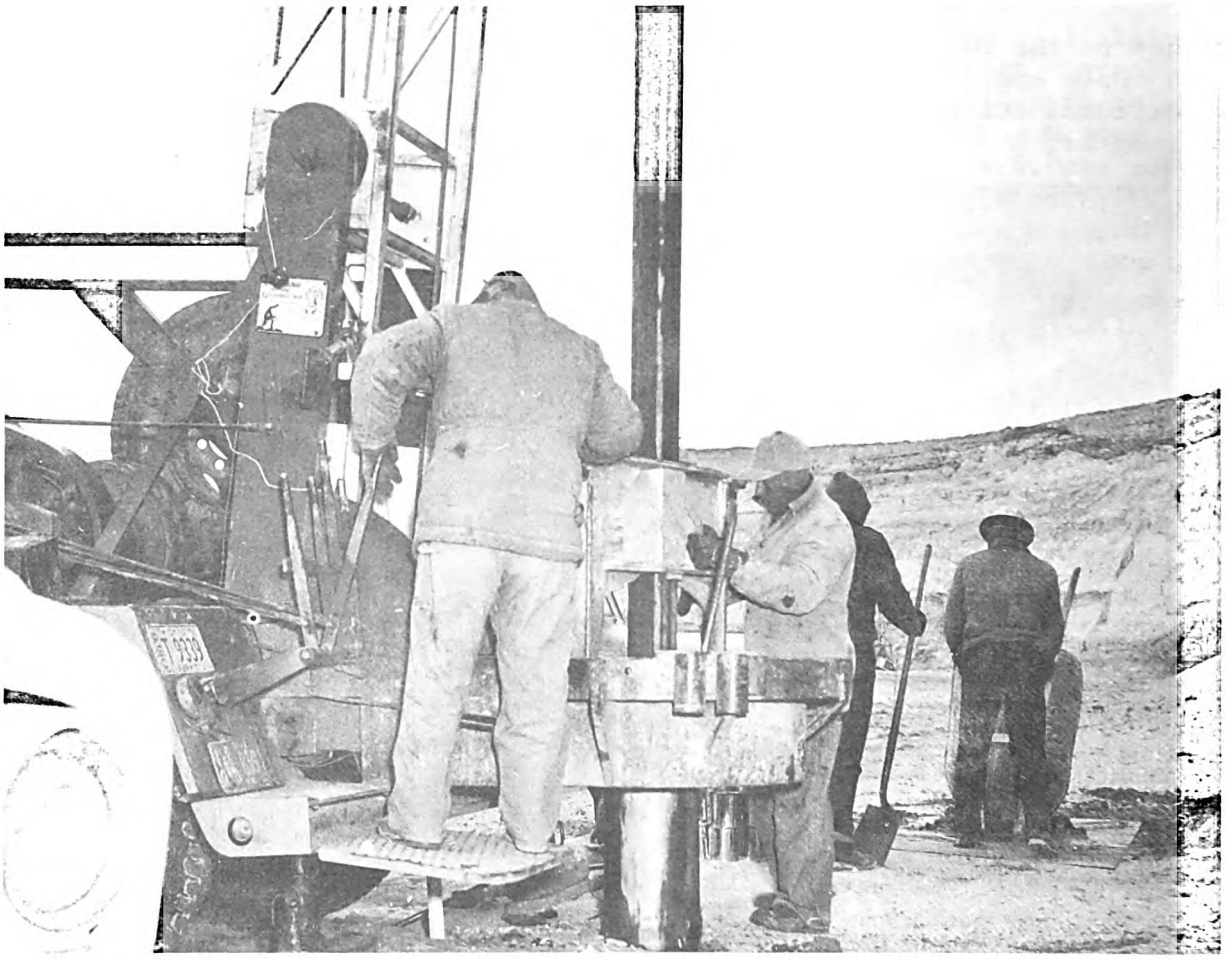

FIGURE 27. - Dropping 12-Inch Bucket Into Hole. Note Scraper-Type Bit on Bottom of 18-Inch Bucket in Right Foreground.

TABLE 15. - Drilling progress with the dry-hole digger[1/]

Depth, feet	Average rates, feet per hour
0 to 40	15
40 to 60	12
60 to 80	9
80 to 100	8
100 to 120	6
120 to 140	5

1/ Formations free from boulders; holes less than 32 inches in diameter.

In extremely wet formations, it was necessary to install a flap valve in the bottom of the bucket to minimize leakage of the wet material as the bucket was withdrawn from the hole. Clean, fine-grained wet sand was the only material encountered that could not be held by the flap valve. Interbedded thin strata of consolidated material can be penetrated by means of a chopping bit.

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A COMPARISON OF NONCORE DRILLING METHODS

Phelps Dodge Corp. conducted an exploratory drilling program in the Crooks Gap uranium area of Fremont County, Wyo., during 1956 and 1957. Three types of truck-mounted drill rigs (rotary-table, swivel-head, and churn-drill) were used to drill an aggregate of 97,558 feet of hole. This footage constituted only part of the corporation's long range exploratory program in the area. The drilling records provide a means of comparing performances in similar formations and under almost identical conditions for the three types of rigs. All drilling was in the Tertiary Wasatch formation, which consists of variegated claystone, arkosic sandstone, and conglomerates. Hard boulders and cobblestones are scattered throughout the formation. Core recovery from the relatively unconsolidated materials was unsatisfactory, so core drilling was discontinued early in the program.

Rotary-Table Drill Rigs

Several rotary-table drill rigs were employed in drilling 83,171 feet of noncore hole. Roller-type rock bits or drag-type bits were used as required for fastest penetration. Bit diameters ranged from 4-1/4 to 4-3/4 inches. Standard 2-3/8-inch drill pipe with 2-7/8-inch-diameter couplings was used when drilling with the rotary-table rigs.

In firm ground above the water table, drill cuttings were blown from noncore holes by means of compressed air. After the water table was reached, the holes were completed with water as the circulating medium. If the walls of the hole tended to cave, a water-base mud fluid was circulated to retard caving and reduce loss of medium.

On the basis of total footage and total shifts spent on the job, the crews that drilled with rotary-table equipment averaged 148.7 feet of hole per 8-hour shift. The maximum advance in one shift was 500 feet; the minimum advance was 20 feet. Holes ranged in depth from 200 to 1,310 feet and averaged 500 feet.

Swivel-Head Drill Rigs

Hydraulic-feed drill rigs, designed primarily for diamond drilling, were used to drill an aggregate of 12,176 feet of noncore hole. The equipment included BX-size drill rods, and drag-type bits or 2-1/2- to 3-inch roller-type rock bits. Maximum hole depth was 800 feet. Average advance was 33.4 feet per 8-hour shift. The equipment apparently was not properly designed for solely noncore drilling with drag-type or roller bits, through loosely consolidated formations containing numerous boulders.

With the same type of equipment, in 1956 a hole was drilled in the Wasatch formation on an adjacent property, to a depth of 2,135 feet.

Churn-Drill Rigs

Truck-mounted churn drills were used to drill 2,211 feet of 6-, 8-, and 10-inch-diameter holes. The average advance was 9.9 feet per 8-hour shift.

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The churn drills were used to obtain accurate samples for milling tests and to check radiometric anomalies discovered in other noncore drilling. Drilling speed was considered unimportant compared to sampling accuracy.

Holes 10 inches in diameter were churn-drilled to the mineralized zone, and an 8-inch casing, with drive shoe attached, was set in the hole. The hole was then deepened in 2-foot intervals with an 8-inch bit. The churn-drill cuttings were removed with a bailer and a sand pump. After the cuttings were removed, the casing was raised about 5 feet, and the 2-foot section of 8-inch hole was reamed to 10-inch diameter. The casing was then lowered to the bottom of the hole, and the reamer cuttings were removed with a sand pump and were discarded. This procedure was repeated for each 2-foot interval.

The diameter of the hole was reduced to 6 inches when the drill operators were unable to complete the hole with 8-inch casing.

Sampling Methods and Reliability

The drill cuttings were saved from each 5 feet of noncore exploratory hole. However, if the radiometric background count doubled, or a known mineralized zone was penetrated, the sample interval was reduced to 2 feet.

Several methods of collecting dry cuttings were investigated in an effort to obtain reliable samples. Dry cuttings discharged from a drill hole by compressed air were caught in an open bucket, but dust losses were high, and the samples were not reliable.

Samples consisting of dry cuttings trapped in cone- or box-type collectors were considered fairly reliable. However, removal of the cuttings from the box-type collector was time-consuming. After some experimenting, a reduced-air-velocity type of dust collector was designed on the job. It consisted of two shallow, semiciruclar pan sections, set below an umbrella-like hood (fig. 6). The dust and rock particles, flushed from a drill hole with compressed air, were deflected from the hood into the pan sections. An extra set of pans allowed drilling to be continued while a sample was being packaged. On windy days, fine-dust loss was reduced by draping a piece of canvas over and around the hood. Samples consisting of dust and rock particles collected in the sample catcher were believed reliable enough for this phase of the exploratory program.

Wet cuttings, discharged from holes in which water or drill-mud was used as a circulating medium were caught in troughs 1 foot deep, 2 feet wide, and 16 feet long. The troughs were semicircular in cross section and were equipped with three removable baffles. The circulating medium was run through one trough during the drilling of one 2-foot interval and through another trough during the next interval. The wet samples were not reliable for determining ore grade but were useful for lithologic correlation.

Churn-drill samples, collected with bailers and sand pumps, were reliable and were used in mill tests and for calibrating radiometric probing equipment. About 100 pounds of cuttings were obtained from a 2-foot section of 8-inch-diameter hole.

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EXPLORATION, PIT PLANNING, AND MINING CONTROL, BY DRILLING AT LUCKY MC URANIUM CORP.

Uranium deposits found in the loosely consolidated sediments of the upper Tertiary Wind River formation in the Gas Hills district, Fremont County, Wyo., are irregular in shape and usually occur within the vertical interval of 30 to 400 feet from the surface.

Primary exploratory holes were drilled noncore on a 500-foot-square grid (fig. 28) and were probed with radiometric equipment. The radiometric results were often checked by chemical analyses of core obtained by the freezing method. In areas where uranium minerals were present, or where geologic conditions were favorable to uranium mineralization, intermediate exploratory holes were drilled on a 100-foot-square grid (fig. 28).

An ore body indicated by an intermediate exploratory hole could be further delineated by drilling four pit-planning holes (fig. 28). Intermediate exploratory holes, as well as pit-planning holes, formed the basis for mapping vertical sections of the ore body. The vertical sections were drawn diagonally to the base grid; thus, the sections were spaced 70.7 feet apart.

Ore-reserve estimates based on 70.7-foot sections were conservative. Ore less than 1 foot thick was excluded, and ore assaying more than 1 percent U_3O_8 was considered as 1 percent ore in the calculations. Table 16 shows how certain estimates compared with production for 1955-56.

TABLE 16. - Ore-reserve estimates compared with ore produced, Lucky Mc mine, 1955-56.

Unit	Estimated		Produced		Excess production over estimate	
	Tons	U_3O_8, percent	Tons	U_3O_8, percent	Tons	U_3O_8, pounds
1.....	4,507	0.15	5,821	0.13	1,314	1,614
2.....	7,879	.21	9,766	.22	1,887	9,879
3.....	9,491	.19	12,208	.19	2,717	10,325

Small ore bodies missed by drill holes were discovered during stripping and accounted for most of the excess production shown in table 16.

After the overburden was stripped to within about 5 feet of the known ore bodies, excavation was stopped. Mining-control holes were then drilled, and additional geologic sections, 35.35 feet apart, were drawn (fig. 28). Holes for mining control usually were drilled less than 30 feet deep by the method considered most suitable from the standpoint of sampling accuracy.

Dry Sampling for Mining Control

Wherever possible, dry-drill cuttings from mining-control holes were collected and sampled. Mayhew 1000 drill rigs were used to drill 4-1/4-inch diameter holes with drag-type or roller-type bits to obtain the dry

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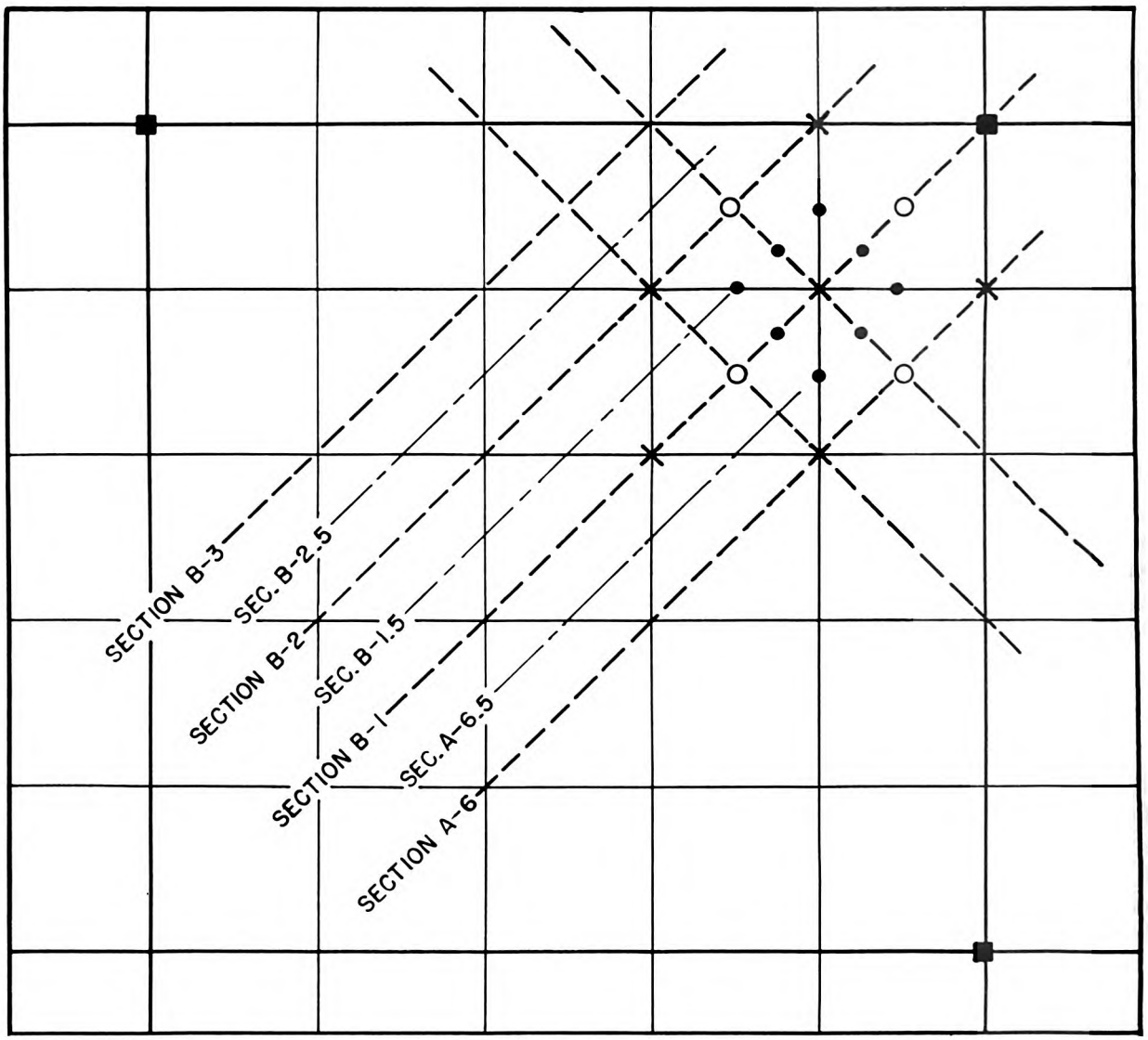

LEGEND

- Primary exploration holes
- Intermediate exploration holes
- Pit-planning holes
- Mining-control holes
- Base grid, 500-ft. centers
- Intermediate grid, 100-ft. centers
- Pit-planning sections, 70.7 ft. apart
- Mine-control sections, 35.35 ft. apart

FIGURE 28. - Drillhole Layout, Lucky Mc Uranium Corp., Fremont County, Wyo.

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samples. Compressed air for removing drill cuttings was furnished by truck-mounted Ingersoll-Rand Gyro Flo compressors rated at 600 c.f.m. One compressor could supply enough compressed air at 60 to 80 p.s.i. to operate two drill rigs. However, the drill rigs commonly were used in areas so widely separated that one compressor was required with each drill rig.

Most of the cuttings were trapped in the reduced-air-velocity sample box shown in figures 7 and 29. Dust not caught in the sample box was trapped in a cone-type dust collector. According to the drill operators, the fine dust trapped in the dust collector constituted less than 0.5 percent of the total sample.

Using Dry-Hole Digger for Mining-Control Sampling

Wherever moisture was present in the softer sediments, the dry-hole digger was used to recover samples for mining-control and pilot-mill tests. Holes 12 or 15 inches in diameter rarely were drilled more than 30 feet deep. Material removed from the holes was split, and a 5-pound sample from each foot of hole was retained for analysis. Most of the reject was used to backfill the hole.

Other Sampling Methods

Calcareous sandstone beds are difficult to drill with the dry-hole digger, so wherever the harder beds occurred in damp formations, the samples were obtained by core drilling. The Christensen core barrel with a pilot-type bit (fig. 30) was quite satisfactory, but in 7,000 feet of drilling, only 200 feet of hole was core drilled. The frozen core method could have been used, but the cost per foot of drilling shallow holes would have been increased because of the added costs for site preparation.

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DESCRIPTION OF MATERIALS AND PARTS FQR LUCKY MC DUST COLLECTOR

Use 12- to 16-gage sheet metal for box construction.

1. Retainer ring. Cut from 1/4-inch stock, not less than 6-inch I. D. held in place with not less than 4 bolts. About 9-inch O. D.

2. Light-duty inner tube or sheet rubber. Held in place by retaining ring. Hole in center of rubber is slightly smaller than O. D. of drill rods or drill pipe.

3. Reinforcing plate. 1/4- or 3/16-inch plate welded to top of box. Plate is 13-1/2 inches square with 6-inch hole in center and holes for retainer-ring bolts.

4. Angle iron brace. 1/8- by 3/4-inch angle iron inside of box top, welded flush with front edge of top. Subsequently faced with strip of sponge rubber, 1/4- or 3/8-inch thick.

5. Latching bars (2). Free to swivel at one end as indicated. Latches fit into hooks No. 10 and hold hinged door snug against sponge-rubber facing.

6. Dust slide construction same as (9) below. Ends must be cut off to allow clearance for dust slide inside box.

7. Press plate. 1/2- or 3/8-inch steel plate. Held on top of item 12 when pressing lower extension of item 12 into undersize hole. Drill rod or kelly rests on the press plate to transmit down pressure.

8. Thin-wall tubing. 3-inch O. D., 4 to 6 inches long, air-dust discharge opening.

9. Dust-slide. Constructed from 1/8- by 3/4-inch angle iron and 1/8- by 1-inch bar stock. Construction details inset.

10. Latch hooks. Formed to fit around angle irons and to ends of box. Welded in place as last structural item. Insures dust-tight closure.

11. Face plate. 1/8- by 3/4-inch angle iron welded outside of box ends and bottom, flush with front edge. Subsequently faced with 1/4- or 3/8-inch thickness of sponge rubber.

12. Stand pipe. 6-inch I. D. standard water pipe. The lower extension is pressed into a smaller hole for a snug fit.

13. Sample tray. Fits inside of sample box below dust slide.

Hinges must be mounted to allow front piece to clear angle iron brace, item (4), by at least 1/8-inch if 1/4-inch sponge rubber is used.

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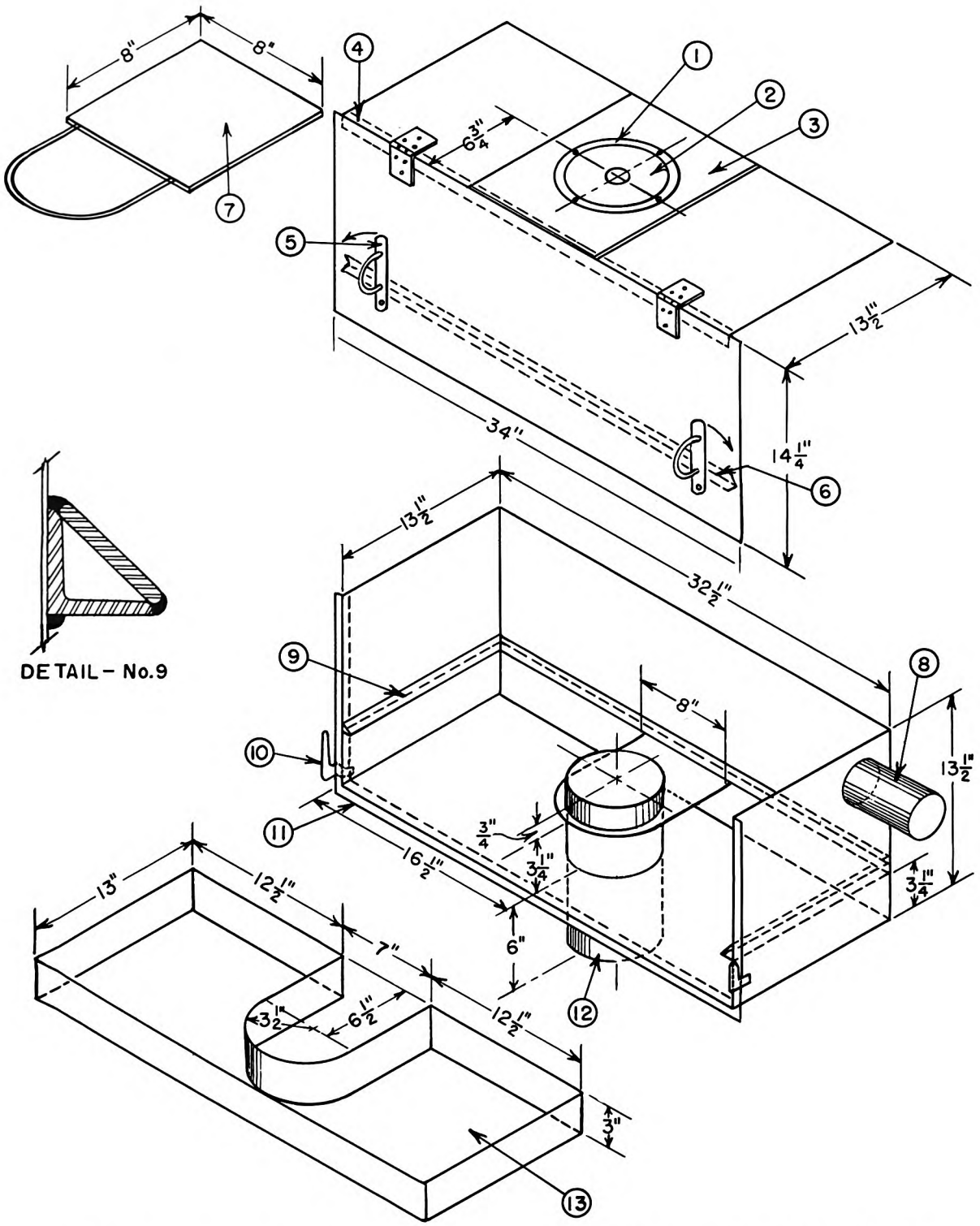

FIGURE 29. - Nominal Dimensions and Structural Details of Lucky Mc Dust Collector.
(Courtesy of Lucky Mc Uranium Corp.)

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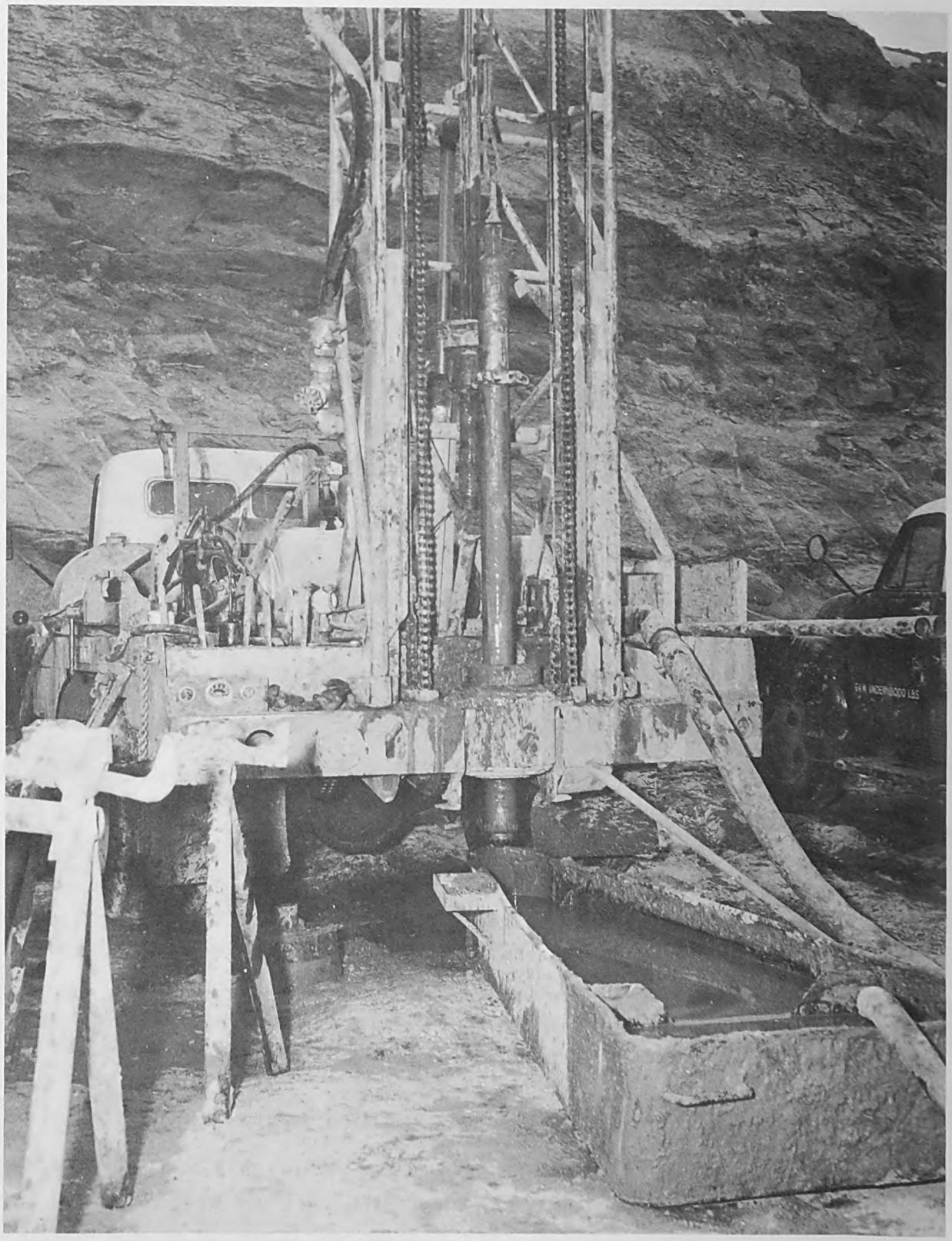

FIGURE 30. - Christensen Core Barrel and Pilot-Type Bit Used to Core-Drill Unconsolidated Sediments for Mining-Control Samples.

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